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TECHNICAL SESSION

THE COMPLEMENTARY RELATIONSHIP BETWEEN POTENTIAL AND AREAL EVAPOTRANSPIRATION: THE WORKINGS OF A NATURAL FEEDBACK MECHANISM

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CONTEXT

The complementary relationship areal evapotranspiration (CRAE) model can provide reliable independent estimates of actual areal evapotranspiration in most parts of the world with no need for locally tuned coefficients (Morton, 1983). The necessary location characteristics are limited to the latitude, the altitude and the long-term average annual precipitation. The required climatological inputs are averages for periods of five days to a month of the humidity (dewpoint or vapor pressure), the temperature (or the average of the maximum and minimum temperatures) and the sunshine duration (or global radiation). The humidity and temperature observations must be accurate and site specific, i.e. in a location that is representative of the area of interest and at least 300 metres from the nearest environmental discontinuity, but the sunshine duration (or global radiation) observations can be made anywhere in the same general area.

The complementary relationship wet surface evaporation (CRWE) model and the complementary relationship lake evaporation (CRLE) model are spinoffs from the CRAE model. The CRWE model can provide estimates of monthly evaporation from lakes with average depths of less than 1.5 m and these - when accumulated over a year or years - can provide estimates of annual evaporation for lakes with average depth of less than 30 m. By the addition of an approximate sub-surface heat storage routing procedure, the CRLE model can provide estimates of monthly and annual evaporation for lakes with average depths of up to 150 m. As in the CRAE model there is no need for locally tuned coefficients. The required inputs are the same as well except that the long-term average annual precipitation is replaced by the salinity (total dissolved solids) of the water and, in the case of the CRLE model, the average depth of the lake. However, the climatological input requirements are not nearly so stringent because the estimates of lake-size wet surface evaporation and lake evaporation are relatively insensitive to errors in temperatures and humidity and because it does not matter much where in the vicinity of the lake the temperature and humidity observations are made.

The conceptual and empirical foundations for the complementary relationship between areal and potential evapotranspiration, the use of the relationship in the formulation of the CRAE model and the test of the CRAE model using water budget estimates of evapotranspiration for 143 river basins in Canada, the United States of America, Ireland, Australia, New Zealand and a number of countries in Africa have been documented in detail elsewhere (Morton, 1983a). Since that time the number of test basins have increased, with one of them providing evidence that the range of application can be expanded to the Amazonian rain forest. A companion paper (Morton, 1983b) presented the formulation of a now outdated version of the CRLE model and a test of the CRWE and CRLE model outputs against comparable water budget estimates for nine lakes in North America and one large in East Africa. The formulation of a revised routing technique for the CRLE model and a test of the CRWE model and the revised CRLE model using water budget estimates of evaporation from sixteen lakes in North America and one lake in East Africa - the only suitable standards of comparison found in a search of the English language literature - are presented in a paper entitled "Practical Estimates of Lake Evaporation" which has been accepted for publication in the Journal of Climate and Applied Meteorology. A detailed documentation of the FORTRAN program for the CRAE, CRWE and revised CRLE models has been published (Morton et al., 1985).

The conventional approach to evaporation problems began with studies of small continuously wet surfaces such as pans, evaporimeters or lysimeters. These studies indicated that the evaporation from such surfaces could be modelled by the potential evaporation, the evaporation estimated from a solution of the energy balance and vapour transfer equations. It then seemed reasonable to model the evaporation from lakes or basin-size vegetated areas using the pan or potential evaporation as a casual agent or a forcing function. Although the underlying assumptions concerning the soil, the vegetation and the atmosphere are now known to be wrong (Morton 1982, 1983a), this continues to be the dominant approach promulgated in textbooks, university courses and the literature. The chief problem is that it ignores feedback mechanisms associated with scale and plant processes which can modify or even reverse small-scale wet-surface processes (Morton, 1986). Because of its inherent lack of reality, this approach requires the use of nebulous coefficients that must be calibrated from existing information. In other words the approach is useless from a practical point of view because it can only provide reasonable looking answers when the answers are already known. The use of the conventional approach has even more serious consequences from a scientific point of view, because its unthinking acceptance by hydrologists and meteorologists perpetuates a narrow, simplistic and incorrect view of natural processes which stultifies attempts to find out what is actually going on.

The complementary relationship mirrors reality in that a decrease in the availability of water for areal evapotranspiration causes the overpassing air to become hotter and drier thereby producing an increase in potential evapotranspiration. This feedback mechanism has great advantages because it permits the actual areal evapotranspiration to be estimated from its effects on the routine temperature and humidity observations required to estimate potential evapotranspiration, thereby avoiding the complexities of the soil-plant system and the need for locally tuned coefficients. However, it has its disadvantages in that it makes the complementary relationship incomprehensible to those that have been brainwashed by the conventional wisdom. Thus, it changes the relationship between actual and potential evaporation from positive for a pan-size wet surface to negative for vegetated areas of 40 hectares or more. In other words an increase in potental evapotranspiration, which is cause for an increase in evaporatoin from a pan-size wet surface, can be an effect of a decrease in evapotranspiration from a field-size or basin-size vegetated area. Because the complementary relationship provides solutions to many practical problems and furnishes a fresh, coherent and realistic frame of reference for the study of hydrometeorological problems, it is essential that this paradoxical feedback mechanism be better understood by the hydrological and meteorological communities.

The workings of the paradoxical feedback mechanism were described in great detail in the main treatise on the complementary relationship (Morton, 1983a). However, the description suffered from the scarcity of data then available to elucidate directly, without intermediate inferences, the effects of the basic feedback mechanism. Further studies have led to the realization that hydrometeorologicaldata from the wet-and-dry tropics provides excellent material for illustrating how the complentary relationship works. This is because the net radiant energy does not vary much throughout the year, the areal evapotranspiration approaches the potential evapotranspiration once humid conditions are well established during a rainy season of five to seven months in duration and the areal evapotranspiration approaches zero once arid conditions are well established during a rainless season of seven to five months in duration. The availability of such data has led to renewed attempts to make the complementary relationship understandable. Two of these attempts, one at the Fall Meeting of the American Geophysical Union in San Francisco on December 3, 1984, and the other at the Ninth Annual Meeting of the Alberta Climatological Association in Edmonton on June 4, 1985, have been oral presentations. However, two more attempts are in the process of being published. One of these is part of the aforementioned paper on lake evaporation which has been accepted for publication in the Journal of Climatology and Applied Meteorology. The other, which is very similar to the oral presentations, will be published in the Proceedings of American Society of Agricultural Engineers Symposium on Advances in Evapotranspiration to be held in Chicago on December 16-17, 1985. A copy of the latter paper is presented as an appendix.

Even though the use of data from the wet-and-dry tropics can make the complementary relationship more understandable, it will still be difficult for hydrologists and meteorologists to put aside the linear logic of cause and effect that presently prevails on blackboards and paper and to accept the circular logic of cybernetic feedback systems that prevails in real environmental systems. However, this change of thinking, which is necessary for an understanding of the complementary relationship, is well worthwhile because it can not only provide a solution to many practical problems but can also open up a fresh, coherent and realistic perspective that has great potential value in the study of all environmental systems.

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Note: This is a copy of a paper published in the Proceedings of the ASAE Symposium on Advances in Evapotranspiration which was held in Chicago on December 16 and 17, 1985.

THE COMPLEMENTARY RELATIONSHIP AREAL EVAPOTRANSPIRATION MODEL: HOW IT WORKS

F.I. Morton*

The complementary relationship areal evapotranspiration (CRAE) model can provide reliable independent estimates of actual areal evapotranspiration in most parts of the world with no need for locally tuned coefficients (Morton, 1983). The necessary location characteristics are limited to the latitude, the altitude and the long-term average annual precipitation. The required climatological inputs are averages for periods of five days to a month of the humidity (dewpoint or vapor pressure), the temperature (or the average of the maximum and minimum temperatures) and the sunshine duration (or global radiation). The humidity and temperature observations must be accurate and site specific, i.e. in a location that is representative of the area of interest and at least 300 metres from the nearest environmental discontinuity, but the sunshine duration (or global radiation) observations can be made anywhere in the same general area.

The conceptual and empirical foundations for the complementary relationship between areal and potential evapotranspiration, the use of the relationship in the formulation of the CRAE model and the test of the CRAE model using water budget estimates of evapotranspiration for 143 river basins in Canada, the United States of America, Ireland, Australia, New Zealand and a number of countries in Africa have been documented in detail elsewhere (Morton, 1983). Since that time the number of test basins has increased, with one of them providing evidence that the range of application can be expanded to the Amazonian rain forest. A detailed documentation of the FORTRAN program for the CRAE model, the associated CRWE (complementary relationship wet-surface evaporation) model and the associated CRLE (complementary relationship lake evaporation) model has been published (Morton et al., 1984).

There have been great difficulties in making the complementary relationship understandable to those working on evaporation problems. This may be because textbooks, university courses and the literature dogmatically inculcate a narrow, simplistic and untested view of hydrometeorological processes, a view which the complementary relationship exposes as false. The lack of understanding is unfortunate because, as has been documented elsewhere (Morton, 1983), the CRAE model is demonstrably much superior to its conventional alternatives in its conceptual and empirical basis and in its ability to produce reliable independent estimates of actual areal evapotranspiration from routine climatological observations in most parts of the world with no need for locally optimized coefficients. Much of what follows represents a renewed attempt to expand understanding, using previously published information and a fresh analysis of data from the wet-and-dry tropics to illustrate the workings of the complementary relationship.

Potential applications of the CRAE model have been discussed in some detail elsewhere (Morton, 1983). One possible application - that of detecting and monitoring the differences in evapotranspiration between neighboring field-size areas with different land uses - has received little emphasis heretofore because of uncertainty about the fetch required to overcome the effects of advection near land use boundaries. Because of its potential importance to agriculture, forestry and hydrology, the feasibility of this use is being investigated with the installation of the required instrumentation in adjacent areas of phreatophytes and prairie grass, dryland crops and summer fallow, irrigated and unirrigated crops and standing and cleared forests. Some data collected to date, which provide reasonable grounds to expect that the technique will prove successful, are discussed in a subsequent section.

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THE COMPLEMENTARY RELATIONSHIP - HOW IT WORKS

The complementary relationship between areal and potential evapotranspiration is ET + ETP = 2ETW. This may be rearranged to give

$$ET = 2ETW - ETP \tag{1}$$

in which ET is the areal evapotranspiration, the actual evapotranspiration from an area so large that the effects of upwind boundary transitions, such as those shown later in Fig. 2, are negligible; ETP is the potential evapotranspiration, as estimated from a solution of the vapor transfer and energy-balance equations, representing the evapotranspiration that would occur from a hypothetical moist surface with radiation absorption and vapor transfer characteristics similar to those of the area and so small that the effects of the evapotranspiration on the overpassing air would be negligible; and ETW is the wet-environment areal evapotranspiration, the evapotranspiration that would occur if the soil-plant surfaces of the area were saturated and there were no limitations on the availability of water.

The best known techniques for estimating ETP and ETW are the Penman (1948) equation and the Priestley and Taylor (1972) equation respectively. In the CRAE model, ETP is estimated from a quickly converging solution to the energy balance and vapor transfer equations and ETW is estimated from the Priestley and Taylor equation as adjusted to take into account the effects of large scale advection during winter. The two coefficients needed for the adjustment and the vapor transfer coefficient needed in the computation of ETP were derived (Morton, 1983) from data for dry months in arid regions where the sum of ETP and the precipitation approximates 2ETW.

Schematic Representation

Figure 1 provides a schematic representation of Eq. (1) under conditions of a relatively high radiant-energy supply (solid line) and a relatively low radiant-energy supply (dashed line). The ordinate represents evapotranspiration and the abscissa represents water supply to the soil-plant surfaces of the area, a quantity that is usually unknown. When there is no water supply to the soil-plant surfaces (extreme left of Fig. 1) it follows that ET = 0, that the air is very hot and dry and that ETP is at its maximum rate of 2ETW (the dry environment potential evapotranspiration). As the water supply to the soil-plant surfaces of the area increases (moving to the right in Fig. 1) the resultant equivalent increase in ET causes the overpassing air to become cooler and more humid which in turn produces an equivalent decrease in ETP. Finally, when the supply of water to the soil-plant surfaces of the area has increased sufficiently, the values of ET and ETP converge to that of ETW.

The conventional definition for ETP is the same as the definition for ETW. However, the potential evapotranspiration that is estimated from a solution of the vapour transfer and energy-balance equations reacts to changes in the water supply to the soil-plant surfaces in a way similar to those shown for ETP in Fig. 1, so that what is being estimated can exceed what is being defined by as much as 100%. By taking into account such reactions, the

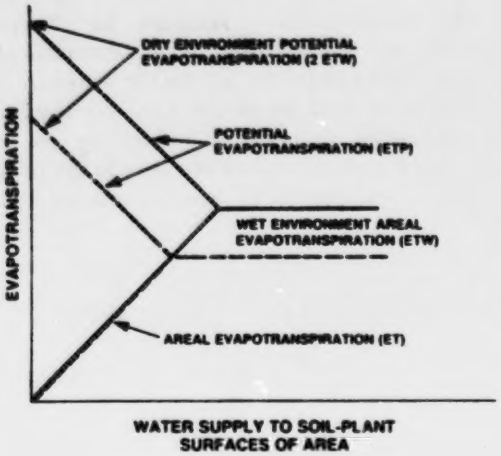

Fig. 1 Schematic representation of complementary relationship

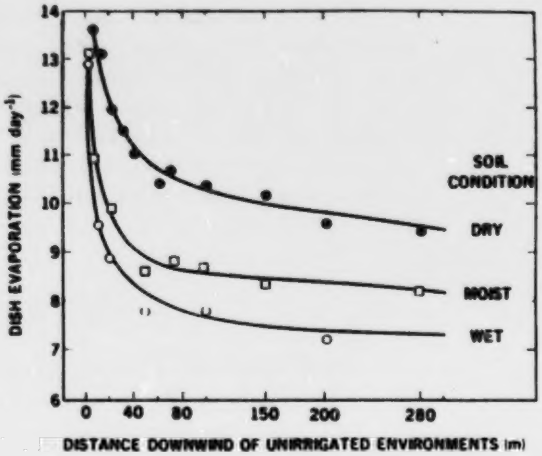

Fig. 2 Dish evaporation across three cotton fields on the same day (Davenport and Hudson, 1967)

complementary relationship is analogous to the Bernoulli equation for open-channel flow in which the potential energy responds in a complementary way to changes in kinetic energy.

The CRAE model is based on Eq. (1) in which the left-hand side, a product of complex and largely unknown processes and interactions in the soil-plant-atmosphere continuum, is estimated from its effects on the temperatures and humidities needed to estimate the right-hand side. It may be noted that there is a negative (complementary) relationship between the actual areal and the potential evapotranspiration in Eq. (1), a concept that is diametrically opposed to the assumed positive relationship that is promulgated in textbooks, university courses and the literature.

Dish Evaporation Representation

Data that demonstrate the workings of the complementary relationship are rare. One good set has been provided by Davenport and Hudson (1967), who measured the variation in evaporation across a series of irrigated and fallow fields in the Sudan Gezira, using fiberglass dishes with black-painted wells 113 mm in diameter and 36 mm in depth. The dish evaporation provided a somewhat distorted reflection of ETP. The passage of air from the desert (or from the unirrigated fallow fields) over the irrigated cotton caused the dish evaporation above the cotton to decrease rapidly in the downwind direction and to approach a low constant value within 300 m, the width of the fields. Furthermore, as the air passed from irrigated cotton across unirrigated fallow, the dish evaporation above the fallow increased rapidly in the downwind direction and approached but did not reach the value observed at the upwind edge of the irrigated area. Fig. 2 shows the variation of dish evaporation across three irrigated fields on December 27, 1963. The description of the soil condition is presumably based on visual inspection and is related to the number of days since the last irrigation. Thus it is reasonable to assume that the availability of water, and hence the actual evapotranspiration, is greater in the "moist" field than in the "dry" field and that it is somewhere near its maximum possible value in the "wet" field.

Near the upwind edge of the irrigated fields, where the dish evaporation decreased rapidly, the hot dry air from the desert (or the unirrigated fallow) lost heat and gained vapour from contact with the transpiring cotton leaves. Downwind from the transitional zone, where the dish evaporation approached a low constant value, the observed effects of the evapotranspiration on the temperature and humidity of the overpassing air were well developed and approaching equilibrium. As it is only in an equilibrium zone that the term areal evapotranspiration has any meaning, the minimum size of an area for which the term is applicable is one in which the edge effects in the upwind transitional zone become insignificant.

The ratio of daily dish evaporation at the downwind edges of the individual irrigated cotton fields to that at the upwind edge of the irrigated area was 0.69 for the field with "dry" soil, 0.60 for the field with "moist" soil and 0.53 for the field with "wet" soil. This provides good evidence that the dish evaporation, and presumably ETP, respond negatively to the changes in ET induced by changes in the availability of water. Furthermore the ratio of dish evaporation at the downwind edge of the wet field to that in the upwind desert approached the value of 0.5 predicted by the complementary relationship for the ratio of potential evapotranspiration in a wet environment (ETW) to that in a dry environment (2ETW).

Hydrologic Representation

The workings of the complementary relationship are also demonstrated in Fig. 3, which has been prepared from monthly data for Basin 7 in the Sanguéré area of Cameroon (Casenave, 1978). The demonstration period is the year from April 1, 1974 to March 31, 1975, during which the rainfall was 1114 mm, the runoff was 74 mm, the monthly temperatures ranged from 24.9°C in January to 32.9°C in March and the monthly relative humidities ranged from 84% near the end of the wet period in September to 32% near the end of the dry period in March.

In the bottom panel of Fig. 3(A) the solid line is a plot of the differences between monthly precipitation and monthly runoff (P-Q), a reasonable representation of the water available for evapotranspiration if the carry-over of soil moisture and groundwater from the 7 month rainy season (April to October) to the 5 month rainless season (November to March) is ignored; the dotted line is a plot of the monthly CRAE estimates of ETP, reflecting the effects of month-to-month variations in net radiation, temperature and humidity; and the dashed line is a plot of the monthly CRAE estimates of ETW, reflecting the effects of month-to-month variations in net radiation and, to a much lesser extent, the temperature. In the top panel of Fig. 3(A) the solid line shows the month-to-month variations in the ratio of ETP to ETW and the dotted line shows the month-to-month variations in the ratio of EPN, the more widely known Penman (1948) representation of potential evapotranspiration, to EPT, the more widely known Priestley and Taylor (1972) representation of wet environment areal evapotranspiration. During the year ending March 31, 1975, the ratios ETP/ETW and EPN/EPT varied from minima near 1.0 once the rainy season became well established to maxima of somewhat less than 2.0 once the rainless season became well established. The immediate reasons for this seasonal pattern are the responses of ETP (or EPN) to changes in the relative humidity which had average values of about 0.82 during the rainy season and about 0.35 during the rainless season. However, the ultimate cause was the variation in the availability of water for areal evapotranspiration from some value greater than the availability of energy during the rainy season to some value approaching zero during the rainless season. The way that this controls the temperature and humidity of the overpassing air and the ratio of ETP to ETW (or of EPN to EPT) is the essence of the complementary relationship and corresponds almost exactly to its predictions for the transition from wet to dry environments, as shown schematically in Fig. 1.

In Fig. 3(B), as in the bottom panel of Fig. 3(A), the solid line is a plot of the monthly values of P-Q, the rainfall less runoff. However the top dashed line is a plot of the monthly CRAE estimates of 2ETW and the lower dotted line is a plot of the monthly CRAE estimates of ET. The latter quantities are estimated from the former quantities by subtracting the

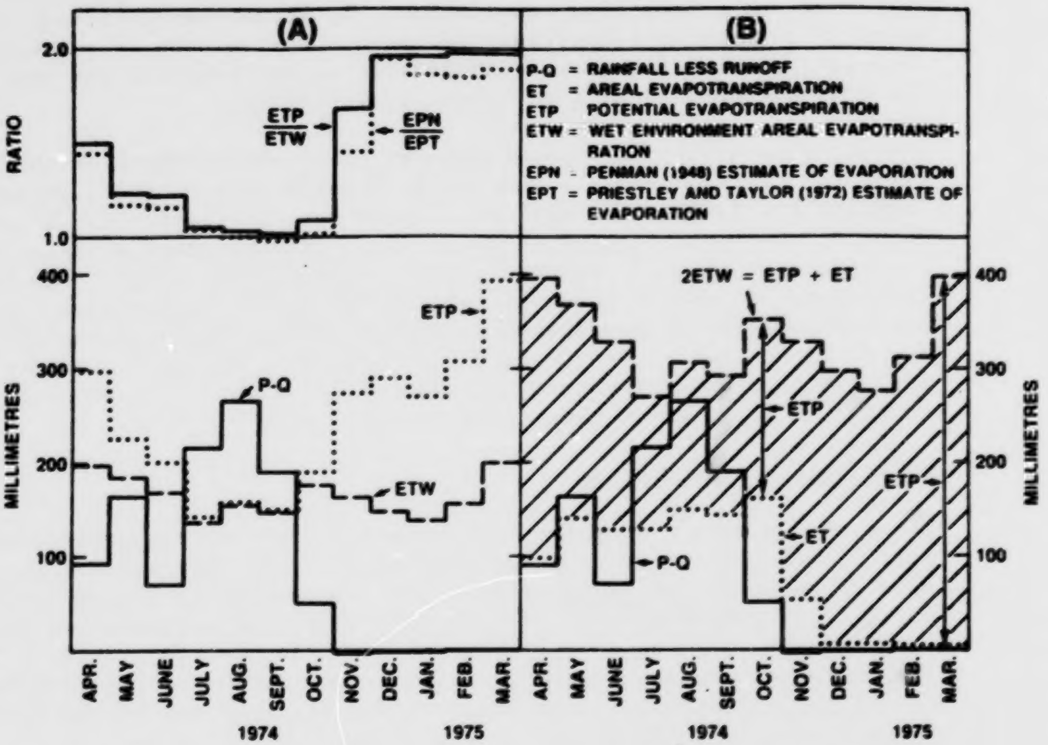

Fig. 3 Workings of the complementary relationship at Station 7 in the Sanguéré, Cameroon

monthly CRAE estimates of ETP as required by Eq. (1). The monthly values of ETP are denoted in a general way by the hatched area between 2ETW and ET and in a specific way for the months of October, 1974, and March, 1975. The plots show how the CRAE estimates of ET respond to changes in the water available for evapotranspiration. Thus ET reached high, relatively constant values once the rainy season became well established in May and reached very low values, approaching zero, once the rainless season became well established in December. The lag of approximately one month between P-Q and ET can be explained by the carryover of groundwater and soil moisture from the rainy season to the rainless season. The highest ET occurred in October, a transition month when the clear skies associated with the end of the rainy season permitted an increase in net radiation while there was still ample moisture in the soil. During the year ending March 31, 1975, the CRAE estimates of ET were 1027 mm and the P-Q estimates were 1040 mm, a difference of only 1.3%.

Comment

Figures 1, 2 and 3 have been prepared specifically to illustrate the workings of the complementary relationship. To derive full advantage from studying them it is helpful to have an open mind, a mind that has been freed from the narrow, simplistic and untested view of evaporation processes that has been perpetuated in textbooks, university courses and the literature. The effort that is needed to gain such freedom is well worthwhile because the complementary relationship provides a fresh, concrete and realistic frame of reference with which to approach the scientific and practical problems of hydrology.

THE COMPLEMENTARY RELATIONSHIP - NEW APPLICATIONS

The potential applications of the CRAE model to water balance studies, to hydrological forecasting, to detecting the development of errors in hydrometeorological records, to detecting and monitoring the effects of land use changes on ET and basin runoff, to estimating long-term average runoff from climatological observations and to providing the ET component for watershed models have been discussed elsewhere (Morton, 1983). Another possible application - that of detecting and monitoring the differences in ET between neighboring field-size areas with different land uses - has received little emphasis heretofore because of uncertainty about the fetch required to overcome the effects of advection near land-use boundaries. Because of its potential importance to agriculture, forestry and hydrology and because an initial study indicated a reasonable probability of success, the feasibility of this use is being investigated further with the installation of the required instrumentation in adjacent areas of dryland crops and summerfallow; irrigated and unirrigated crops and standing and cleared forests.

The initial study was part of an investigation of channel losses from the Milk River in the semi-arid shortgrass prairie region of southern Alberta, Canada (49°N, 111°W). The evaporation from the surface of the river, the largest loss, was estimated from the aforementioned CRWE model (Morton et al., 1984). However there was some concern that the evapotranspiration from large areas of obviously phreatophytic vegetation along the river channel and from even larger areas of low-lying grass and sage in the river valley could be contributing significantly to the reduction in river flow. In order to investigate these possibilities, temperature and dewpoint recorders - each comprising a two channel recorder with dewcel and temperature sensors, solar panel, battery and extra memory pack - were installed in representative sites. The phreatophyte site was in an area of cottonwoods, willows, other woody vegetation and grass with a fetch of 200-250 m to both the dry grassy valley wall and to the river; the riparian site was in a flat area of prairie grass and sage only 2-5 m above the river level with a fetch of 300-400 m to both the valley wall and the river; and the prairie site was in a large area of grass and sage on the upland prairie approximately 400 m from the valley wall. The sunshine duration and precipitation values used in the study were averages for two stations located 40-60 km to the east and west of the sites.

Some results for the hot, dry summers of 1983 and 1984 are presented in Fig. 4 as mass curves of accumulated precipitation and CRAE estimates of ET. The zero values for the accumulations are at midnight May 18-19. The ordinates of the mass curves represent volumes whereas the slopes represent rates. In Fig. 4 the difference between the mass curves of prairie ET and precipitation can be interpreted as the volume of water abstracted from storage in the unsaturated soil of the root zone during the period beginning at midnight May 18-19 and the difference between the mass curves of phreatophyte and prairie ET can be interpreted as the volume of additional water abstracted from soil moisture and groundwater by the phreatophytes during the same period.

Figure 4 indicates that the difference between phreatophyte and prairie ET is surprisingly low. Such a small difference could be due to the contamination of the dewpoints and temperatures at the phreatophyte site by air from dry grass-covered valley walls located significantly less than 300 metres away from the instruments. However, the estimates of phreatophyte ET are higher than those derived from daily groundwater fluctuations at the phreatophyte site, using a technique suggested by White (1932) and standardized by Meyboom (1967), by an amount sufficient to account for evaporation from the soil above the capillary zone. Although the concept that phreatophyte ET may be only slightly higher than that from prairie grass seems counter-intuitive, it is supported by research (see review by Morton, 1984) which indicates that hot dry air, such as that which prevailed in the Milk River area during 1983 and 1984, can cause stomata to close and that such closure, which is more apparent for tree leaves than for grass leaves, can occur even when there is ample water in the root zone.

Although the foregoing discussion has been ambivalent about the viability of the technique, the following aspects of Fig. 4 are more positive:

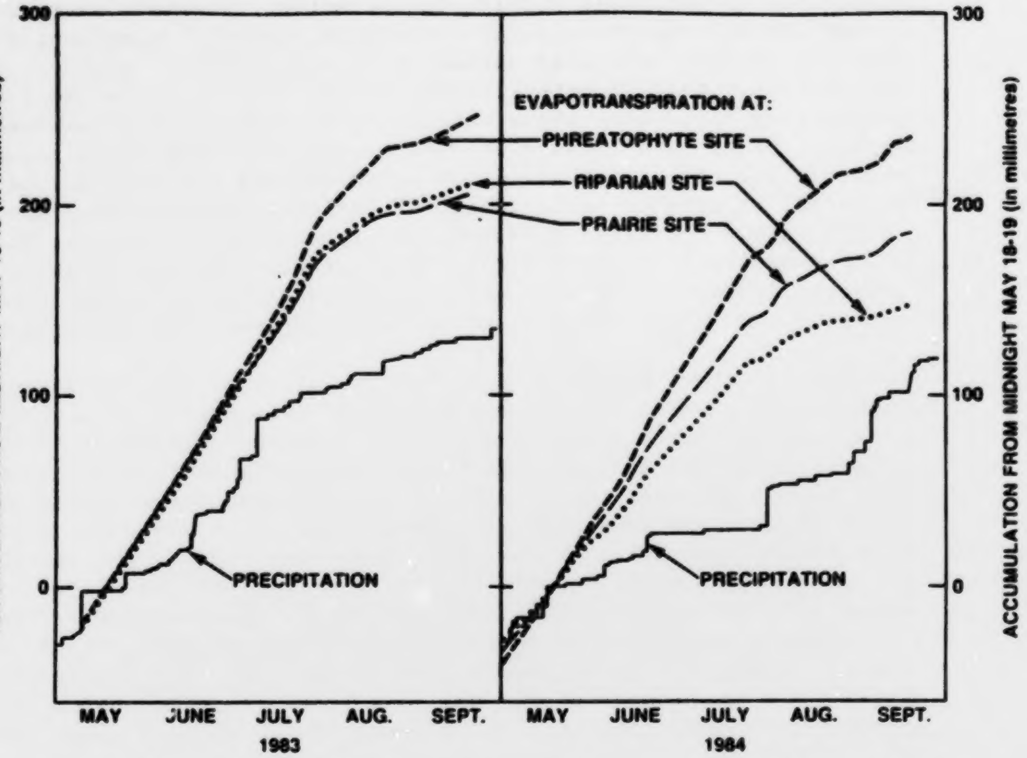

Fig. 4 Accumulated areal evapotranspiration and precipitation near the Milk River, Alberta, Canada.

(1) The differences in the relationship between the mass curves of phreatophyte and prairie ET during 1983 and 1984 can be explained by differences in precipitation patterns and magnitudes. Thus the reason why the two mass curves diverge more quickly between May 19 and July 24 of 1984 than between May 19 and July 24 of 1983 is that the precipitation for the former period was much less than that for the latter period. Furthermore the opposite tendency is evident for the periods after July 24 during which the precipitation for 1984 was significantly greater than the precipitation for 1983. This demonstrates that the CRAE model, when used in conjunction with an automatic temperature and dewpoint recording system, can detect and monitor the different effects of variations in the availability of water on phreatophyte and prairie ET.

(2) The riparian ET was slightly higher than the prairie ET during 1983 and significantly lower during 1984. The reason for the latter difference was quite evident during a visit to the riparian site on July 16, 1984, by which time the grass had been grazed and trampled into bare soil by cattle kept near the river too long because of the drought. The demonstrated ability of the technique to detect and monitor the effects of overgrazing in the Milk River Valley provides reasonable evidence that it can be used to detect and monitor other land-use changes.

The foregoing discussion of Fig. 4 indicates that the CRAE model, when used with an automatic temperature and dewpoint recording system, has considerable promise in studies of evapotranspiration for different land uses on a field-size scale. It is hoped that the experiments now underway, with the required CRAE model inputs and back-up water budget data for neighboring areas of dryland crops and summerfallow, irrigated and unirrigated crops and standing and cleared forests, will provide more conclusive evidence concerning the feasibility of the technique.

CONCLUDING COMMENTS

The foregoing sections have focused on making the complementary relationship between areal and potential evapotranspiration more understandable and in reporting progress on a feasibility study of a previously unpublished application. The latter has been by far the easier task because the former requires the reader to put aside the linear logic of cause and effect that prevails on blackboards and paper and to accept the circular logic of cybernetic feedback mechanisms that prevails in environmental systems. Thus the Penman (1948) equation, which serves as a cause of evaporation from a small moist surface, is, because of a feedback mechanism related to scale, an effect of the evaporation from a large vegetation covered surface. In this example the relationship between actual and potential evaporation changes from positive on a small scale to negative on a large scale. Although the required change in thinking is difficult to make, it is well worthwhile because it opens up a perspective on environmental systems that has great potential value.

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CLIMATOLOGY
and the
THE ALBERTA WATERSHED RESEARCH PROGRAM

Avard Mann

ABSTRACT

A summary of the objectives of the Alberta Watershed Research Program is presented. Significant features of a project to consolidate and catalogue hydrometeorological research results and climatological data are described.

Introduction

The Alberta Watershed Research Program (AWRP) was developed in the early 1960´s through the joint efforts of several federal and provincial agencies which shared a concern for water supplies on the prairies. It was estimated that over 85% of the water flowing in the Saskatchewan River system originated in the foothills and mountains of western Alberta and the concern was that forest clearing for wood pulp, lumber and agriculture in this zone would affect its water yield potential.

It was concluded, therefore, that a program would be initiated to examine the relationships between climatic and topographic factors, forest cover and water yield. In broad terms the objective was to:

> Develop and test land management methods to improve and sustain water yield, quality and regime in the Saskatchewan River headwaters through:
>
> - surveys and inventories
> - gauged watersheds
> - studies of processes which influence water yield such as precipitation, evapotransporation, surface flow and groundwater storage.

Program Operation

The Program was supported by a wide range of government departments and agencies among which were:

Federal	Alberta
Canadian Forestry Service	Alberta Forest Service
Water Survey of Canada	Alberta Water Resources
Canadian Meteorological Service	Alberta Research Council
Agriculture Canada	Alberta Agriculture
Canadian Wildldife Service	Eastern Rockies Forest Conservation Board

and others such as the Prairie Farm Rehabilitation Act (PFRA), University of Alberta and the University of Calgary.

The basis of operation required that each agency develop, fund and carry out its own research program. Coordination was effected through a Research Coordinating Committee (RCC) and through a Research Coordinator appointed by the Canadian Forestry Service.

In 1962 the first gauged watershed was selected, Marmot Creek, representing alpine and sub-alpine spruce-fir forest. The Streeter Creek basin in the

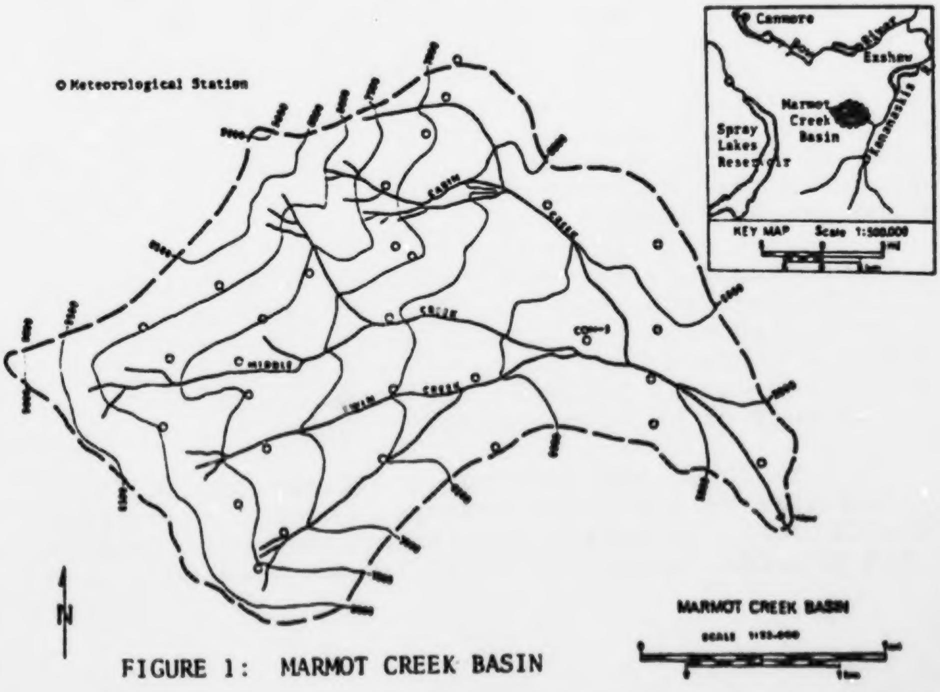
Meteorological Station
Canmore
River
Exshaw
Marmot Creek Basin
Spray Lakes Reservoir
Kananaskis
KEY MAP
Scale 1:500,000
Cabin
Creek
Middle
Twin
Creek
N
MARMOT CREEK BASIN

FIGURE 1: MARMOT CREEK BASIN

Porcupine Hills was identified in 1963 as representative of the foothills forest-grassland regime. The Deer Creek basin near the Red Deer River west of Sundre was the third basin selected and it represented lodgepole pine cover in moderate topography. This latter basin was not fully exploited for watershed purposes due in part to accelerated research in lodgepole pine harvesting techniques in the Hinton area.

Installation of meteorological instrumentation and stream guages started in Marmot Creek in 1962. In 1967 a 150′ meteorological tower was installed in the lower part of the basin to measure solar radiation and wind above the forest canopy. The first research papers were published in 1963.

Research Results

The complexity of the Program both in terms of the diversity of scientific studies and the number of research agencies participating made it difficult to consolidate research results on an ongoing basis. It was almost inevitable that some data and results of some studies would become misplaced in agency archives and buried in little known scientific journals. To compound the problem, up to 1980 very little of the data was recorded or archived in computer accessible form, a feature that has plagued current users of these data.

At an early stage in the Program, however, Water Survey of Canada (WSC) undertook to publish an annual summary of all hydrometeorological data collected on the three research basins. Although each participating agency was responsible for the quality control and archiving of its own data, the WSC annual summaries represents the most comprehensive list of data gathered in the project areas.

Unfortunately there was no similar record of published research results. The proceedings of the 1977 conference on the Alberta Watershed Research Program which was held to review the current status of the Program does , however, include an excellent bibliography of relevant research papers.

At its June 1984 meeting, the Steering Committee for the Alberta Watershed Research Program recognised the difficulty to assess Program achievements relative to the original objectives. It recommended that each agency prepare a summary of research results and a catalogue of data collected in the basins.

The following sections describe summaries prepared for hydrometeorological research reports and a catalogue of data sources. They are available through the Scientific Division, Atmospheric Environment Service, Edmonton, and the Technical Services Division of Alberta Environment.

Hydrometeorological Studies

The review of hydrometeorological studies includes some 66 papers. It appears that research activity peaked around 1970 and reached a low in 1979-80. However one paper in 1982 and two in 1984 indicate that the extensive data set is being re-examined by current researchers. Two of the most recent papers deal with the application of data to verifiy or develop hydrometeorolgical models and one applies the data to an updated and refined area climatology.

In addition, results of some of the previous studies are finding direct application to the development and operation of the adjacent olympic ski area. These include studies of temperature-elevation and snowpack-elevation relationships and wind distribution of snow.

Although all papers are directly related to hydrometeorology they cover a wide spectrum of topics with this field such as:

- inovative instrument techniques
- energy balance in a forest
- refinement of E-T as a water budget term
- groundwater-streamflow relationships
- effects of clearing patterns on snowpack and melt rates
- optimum cutting patterns for streamflow and wildlife.

Hydrometeorological Data

The significant features of the data set are:

- length of record: 1962-1985
- continuity (except of insturment malfunction)
- quality: data were used for research papers

- density and elevation coverage

The one disadvantage of the data set for current users is that virtually all data were recorded on charts and manually transcribed to standard forms. Some data have been transferred to magnetic tape in recent years and most data are now being acquired by data loggers in computer compatable form.

Where data have been transcribed to magnetic tape the original records are kept for future reference. There are some 32 boxes and two filing cabinet drawers full of these original records of precipitation, wind, solar radiation and temperature.

The magnitude of the data available can be judged from examples from Marmot Creek:

Temperature:	11 sites maintained year-round 10 more sites, summer only
Precipitation:	3 recording sites 11 storage gauge sites 24 sites, summer only
Wind:	2 sites, continuous record
Radiation:	RF1 and RF4 at one site, continuous record
Evaporation:	one site, summer only
Snow Courses:	20 sites reduced to 7 after 1968

The continuing data gathering program currently comprises the following:

Streeter Basin:	2 Fischer-Porter Gauges 1 storage gauge
Marmot Creek:	4 sites are maintained: Con 5, Cabin 5, Twin 1 and Twin 3 with: Fischer-Porter precipitation gauges CR-21´s measuring: - temperature - RH - wind - solar radiation

A summary of data collected at Marmot Creek and Streeter Basin is illustrated in appendices to this report.

Acknowledgements

Since this Program started out and continues to operate as a cooperative Federal-Provincial program the interest in, and responsibility for, research results is shared by several agencies. I am therefore grateful to many people in many agencies for their assistance in conducting this survey of research results and archived data. In particular, however, I would like to acknowledge the direct support of Elliott Kerr, Technical Services, Alberta Environment, Dr. R.W. Swanson, Canadian Forestry Service, and Mr. W.D. Hume, Atmospheric Environment Service.

SNOW COURSE DATA - MARMOT CREEK

AES - WSC Publications

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-------------------------------------------------------------------
|             |                       Year                        |
|-------------|---------------------------------------------------|
| Site        |        ´65       ´70       ´75       ´80       ´85|
| Elevation m.| . . . . | . . . . | . . . . | . . . . | . . . . |
|-------------|---------------------------------------------------|
|             |                                                   |
| 1.  (1778)  |   |---------------------------------------|       |
|             |                                                   |
| 2.  (1780)  |   |-----------|                                   |
|             |                                                   |
| 3.  (1780)  |     |---------------------------------------|     |
|             |                                                   |
| 4.  (1823)  |       |-------|                                   |
|             |                                                   |
| 5.  (1750)  |       |-------|                                   |
|             |                                                   |
| 6.  (1780)  |       |-------------------------------------|     |
|             |                                                   |
| 7.  (1798)  |       |-------|                                   |
|             |                                                   |
| 8.  (1832)  |       |--------------------------------|          |
|             |                                                   |
| 9.  (1865)  |       |-------|             |---------------|     |
|             |                                                   |
|10.  (1875)  |       |-------|                                   |
|             |                                                   |
|11.  (1875)  |       |-------------------------------------|     |
|             |                                                   |
|12.  (1951)  |       |-------|                                   |
|             |                                                   |
|13.  (2015)  |       |-------|                                   |
|             |                                                   |
|14.  (2149)  |       |-------------------------------------|     |
|             |                                                   |
|15.  (2118)  |         |-----|                                   |
|16.  (2289)  |       |-------|                                   |
|             |                                                   |
|17.  (2240)  |       |-------|                                   |
|18.  (2188)  |         |-----------------------------------|     |
|19.  (2396)  |             |-------------- ----------------|     |
|             |                                                   |
|20.  (2356)  |           |-| |-|         |-----|                 |
|             |                                                   |
|21.          |               |-----------------------------|     |
|             |                                                   |
|22.          |               |-------------------|               |
|             |                                                   |
-------------------------------------------------------------------
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STORAGE GAUGE DATA

WSC Publication

```
 ----------------------------------------------------------------------
|           |                  Year                                    |
|-----------|----------------------------------------------------------|
| Site      |        ´65         ´70         ´75         ´80       ´85 |
|           | . . . . | . . . . . | . . . . . | . . . . . | . . . . |  |
|-----------|----------------------------------------------------------|
| Twin 1    |       |---------------|                                  |
| Twin 2    |       |---------------------------------------|          |
| Twin 3    |       |---------------------------------------|          |
| Twin 9    |           |-----------------------------------|          |
| Twin 11   |           |-----------------------------------|          |
| Main 4    |       |---------------------------------------|          |
| Main 6    |           |-----------------------------------|          |
| Cabin 2   |       |---------------------------------------|          |
| Cabin 5   |         |-------------------------------------|          |
| Cabin 9   |           |-----------------------------------|          |
|           |                                                          |
|           |                                                          |
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SNOW PILLOW CHARTS, GRAPHS
Canadian Forestry Service

WSC Publications

```
-----------------------------------------------------------------------------------------
|                |                              Year                                    |
|----------------|----------------------------------------------------------------------|
|                | '70  '71  '72  '73  '74  '75  '76  '77  '78  '78  '79  '80  '81  '82 |
|  Site          |  |    |    |    |    |    |    |    |    |    |    |    |    |    |  |
|----------------|----------------------------------------------------------------------|
|                |                                                                      |
| Eastern        |  |----------------------------------------------------------->>---   |
|   (1789 m)     |                                                                      |
|                |                                                                      |
| Lower          |                 |-------------------------------------------->>---   |
|   (1951 m)     |                                                                      |
| Cabin          |                                                    |-------->>---   |
|   (1963 m)     |                                                                      |
| Cirque         |                 |-------------------------------------------->>---   |
|   (2265 m)     |                                                                      |
|                |                                                                      |
| Middle         |                 |-------------------------------------------->>---   |
|   (2155 m)     |                                                                      |
| Twin 1         |                                         |------------------->>---   |
|   (2278 m)     |                                                                      |
| Top            |                                         |------------------->>---   |
|   (2453 m)     |                                                                      |
|                |                                                                      |
-----------------------------------------------------------------------------------------
```

TEMPERATURE DATA: Daily Max/Min

Location	hard copy	computer archive
WSC Publication	all sites 1963-1980	
Canadian Forestry Service		most sites - punch cards 1964-1968 Con 5, Cabin 5, Twin 1, Twin 3 - VAX 1967-1982
Alberta Environment U of A Computer		Con 1 1970-1980 Cab 5 1970-1982 Con 5 1970-1982 Twi 1 1970-1982 Twi 3 1980-1983

EVAPORATION - Class A pan

Location	hard copy	computer archive
WSC Publication and A E S	Streeter 7 1965-1974 Con 5 1962-1977 Con 1 1971-1973	none

PRECIPITATION

location	hard copy	computer archive
WSC Publication	all daily data 1962-1980 storage guage data	
AES archive	hourly data Con 5 -1962-1981 storage guage data - 11 sites	Con 5 1962-1981
Alberta Environment		Con 5 (daily) 1970-1980
U of A Computer		Storage guages 1970-1980

SNOWPACK DATA

location	hard copy	computer archive
WSC Publications	snow course data	
AES	snow course data 1962-1969	
CFS	snow pillow data 17 sites snow stakes above tree line 1974-83	
CFS		Basin snow grid 1969-1980 (VAX)

SOLAR RADIATION

location	hard copy	computer archive
WSC publications	RF 1, RF 4 Daily total	
A E S	Hourly RF 1, RF 4 1963-1981	Con 5 hourly RF 1. RF 4 1967-1981
C F S		4 sites, hourly 1982 -
Alberta Environment		daily total, RF 1 1970-1982
U of A Computer		"Radiation at a point" model

WIND DATA

location	hard copy	computer archive
WSC Publications	daily mean: Streeter 2,4 (1968-1980) Twin 1,12	
A E S	Hourly data Streeter 2,4 Twin 1,12	Streeter 2,4 1968-79 Twin 1,12 1968-79
C F S		4 sites in Marmot Basin 1982 -

CONTINUING PROGRAM

STREETER: 1 Storage guage

2 Fischer-Porter guage

MARMOT CREEK:

sites: Cabin 5, Con 5,
Twin 1, Twin 3

Fischer-Porter guages by AES

CR 21´s by CFS measuring:

- -temperature
- -RH
- -wind
- -solar radiation

A WINTER SEVERITY INDEX WITH ASSOCIATED CLIMATIC MAPS FOR UNGULATES IN ALBERTA

by

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Edmonton, Ab. T6H-4G4

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1. BACKGROUND

In 1983 Fish and Wildlife Division, Alberta Energy and Natural Resources (ENR) initiated a 5-year wildlife habitat information inventory. It is to serve as a basis for determining the current and future status of the wildlife resource, and will assist the Division in regional planning activities. The map used for the inventory was constructed by Pedocan Land Evaluation (1984). It has the Province divided into 12 ecoregions, which are reduced into 278 habitat subregions.

The major ecoregions were originally mapped by Strong and Leggat (1981). They are characterized by distinctive regional climates as expressed by vegetation. The subregions, however, were mapped using only physical criteria - surficial geomorphology and physiographic areas (L. Knapik, personal communication, 1985). Because of this, the determination of distinct and homogeneous climates at the subregion level is usually not possible as geomorphologic units frequently cross climatic zones and barriers. Notwithstanding these limitations Environmental Climate Services was contracted by ENR to develop:

i) a climate data base for each habitat subregion; and
ii) an ungulate winter severity index (WSI) by subregion (Olson 1984).

2. OBJECTIVES

The intent here is to present maps of the synthesized climate data and the winter wildlife severity index from Olson´s (1984) work. The concept of habitat subregions has been excluded to eliminate the problems discussed above.

The climate data were intended to reflect severe winter conditions so, the 90% confidence limits of the means are reported. Also, it should be recognized that a singular winter habitat index will be limited for its application to all ungulate species because of their individual structural adaptations to the winter environment (Kelsall 1969).

3. METHODOLOGY

3.1 Climate Variables

The data base encorporated values from: Atmospheric Environment Service's (AES) archived observation network, which includes records from airports, towns, Alberta Forest Service lookout towers, ranger stations, and Department of Agriculture sites; and non-archived data from the mission-oriented networks at Marmot Creek Basin and Peace River region. The climate variables and their limits were decided upon in committee with scientists from agencies within ENR and Environment Canada. The monthly values from each station are reported in the index of Olson's (1984) work.

Aspects of the winter environment are generally the limiting factors for the distribution of ungulates in northern climes (Pruitt 1984). Low temperatures are seldom critical to large mammals such as moose (*Alces alces*) or caribou (*Rangifer tarandus*) (Formozov 1946, Russel and Martel 1984) but, severe cold in combination with high wind speeds, deep snow, and insufficient food supplies can have a tremendous impact on ungulate populations (Kelsall 1972). The length of the winter is important to ungulates. Especially in terms of embryonic development. The adults may survive a long winter, but the calving season may be extremely unproductive (Telfer 1984, personal communication).

The following variables and their limits were used in the WSI:

a) Severe Cold: this parameter was defined as degree days per annum less than or equal to -30 C. Mean daily temperature was used as the base value;

b) Annual Snow on Ground: the number of days per annum with snow on ground greater than or equal to 30 cm was used. These data provide an indication of energetics and mobility stresses that ungulates will experience given a deep snowpack;

c) Mild Days in Winter: mild days during winter months reduce or eliminate the snowpack. This is a positive aspect in terms of winter severity to ungulates. The criterion used to define winter mildness was a day between 1 December and 31 March with a maximum temperature greater than or equal to 5 C; and

d) Length of Winter: the length of winter was determined as the number of days between the initiation of cellular destruction in fall due to cold in woody plants (lysis) and green-up in spring. These are explained below:

Initiation of Lysis: the approximate end of the positive energy balance period was taken to be the first date after August when an ambient temperature of -5 C was reached. At this temperature lysis occurs in woody plants (Levitt 1956 and Larcher 1973, in Stewart et al. 1977);

Spring Green-up: the timing of green-up influences ungulate production and over-winter survival rates. It is important to ungulates in terms of browse quality because percentages of crude protein and total digestive nutrients are highest then (Stewart et al. 1977). Each plant species has its own base or threshold temperature, below which it will not develop. A certain number of heat units are necessary for the plant to reach stages in its development. Because of the variations in plant distributions throughout Alberta the growing degree day concept was not considered appropriate. A less species-specific criterion was employed. Green-up was considered to be the Julian calendar date of the fifth day of the first consecutive 5-day period after March 31 with mean daily temperatures greater than or equal to 5 C.

3.2 Data Synthesis and Analysis

Records from 103 stations were analyzed. Most of the data are stored on AES's AS/6 computer in Downsview, Ontario. The Peace River records are archived on the Province's computing facilities, while Marmot Creek data only existed on hard copy. All data were normalized using the difference and ratio techniques (AES 1982).

Severe winters were considered to give the best index of winter stresses on ungulates. Thus, the 90% confidence levels of the means were used in all cases.

3.3 Data Limitations and Extrapolations

It is desireable to locate climate stations at sites which are representative of their surrounding environment. The observations from a well selected station on Alberta's prairies may be representative of the atmospheric conditions found in a radius of 40-80 km. But in hilly or mountainous terrain different climate regimes can exist within a very small area (Lester 1974, Yoshino 1975, Janz and Storr 1977, Olson 1983). This is ultimately due to the unequal partitioning of energy as a result of varying topographic and vegetative characteristics (Geiger 1965).

In many parts of Alberta the climate stations are located along valley bottom access corridors or on topographic rises where forest fire lookout towers are situated. But, the atmospheric observations from these stations might not be representative of the conditions at nearby sites (Barry 1981, Janz and Storr 1977, Olson 1983). Care must be taken when identifying the values from these sites as being typical of the surrounding areas, especially if there are differences in aspect, slope angle, elevation or vegetation cover (Powell and MacIver 1978, MacHattie 1970).

Proven techniques for determining the optimum placement of climate stations are available for regions with homogeneous features, but not for areas with complex terrain. The effects of topography on atmospheric variables must be understood to adapt these techniques to hilly or mountainous terrain (McCutchan et al. 1981). Methods of extrapolation should consider elevation, topographic setting, and vegetation cover (Stienhauser 1967).

The effects of topography and elevation were considered in extrapolating the climate variables. The methods in this study largely relied on interpolation between two climate stations, with elevation as the independent variable. However, subjective interpolation was necessary due to the diversity of topography and vegetation cover (Janz and Storr 1977, Olson 1983).

3.3.1 Temperature Extrapolations

Climate parameters within this category included degree days below -30 C, length of winter, and mild days in winter. The interrelationships between temperature and elevation were determined, using normalized data, for four areas of the province:

a) Mountain Parks: at Marmot Creek there were seven stations with year round data. Their elevations ranged from 1390 m to 2286 m asl;

b) West-central: winter data were available for Snuff Mountain (930 m), which were compared with concurrent values from Grande Prairie A (669 m);

c) Northwestern: year round data have been collected on Mount Watt (701 m). They were compared to nearby Hutch (354 m) and High Level A (338 m); and

d) Northeastern: there was a relatively large elevation difference between Stony Mountain (780 m) and Fort McMurray A (253 m).

3.3.2 Snow on Ground

All of the AES stations that report daily snow on ground are located at relatively low elevations. Comparisons with higher sites were facilitated using data from snow surveys on the east slopes of the Rocky Mountains and the Alberta Oil Sands Environmental Research Program study area in northeastern Alberta. The non-AES sites did not have daily measurements. Thus, their snow depth or water equivalencies were used as guides for comparative purposes.

3.4 Weighting and Standardization of WSI Variables

Four of the original seven variables were used in the WSI: very cold days (degree days <= -30 C); mild winter days (T max >=5 C); length of winter; and annual snow on ground. In committee the weighting values were decided. The combination of 30-30-20-20%, repectively, was used in the final analysis.

The ranges and values of the raw WSI climate variables had to be standardized in order to be used in the index. To facilitate this the numbers were arithmetically shifted so that the lowest datum of each parameter had a value of 1. Then, the ranges were transformed to fall between 1 and 100, inclusive. This worked well for three of the four parameters. Mild days during winter was a positive attribute in the index while the others were negative. To be consistent the number of mild days was transformed twice more: 100 was subtracted and then the absolute values were calculated.

The final transformations involved dividing each of the variables by four and then summing them. Theoretically the resultant indices range from 1 to 100. The lower values have less severe and the higher have more severe winter climates.

4. RESULTS

Maps of the four climatic variables used in the determination of the WSI and the distribution of the index itself are presented (Figures 1 to 5). Following is a discussion of each map:

4.1 Severe Cold

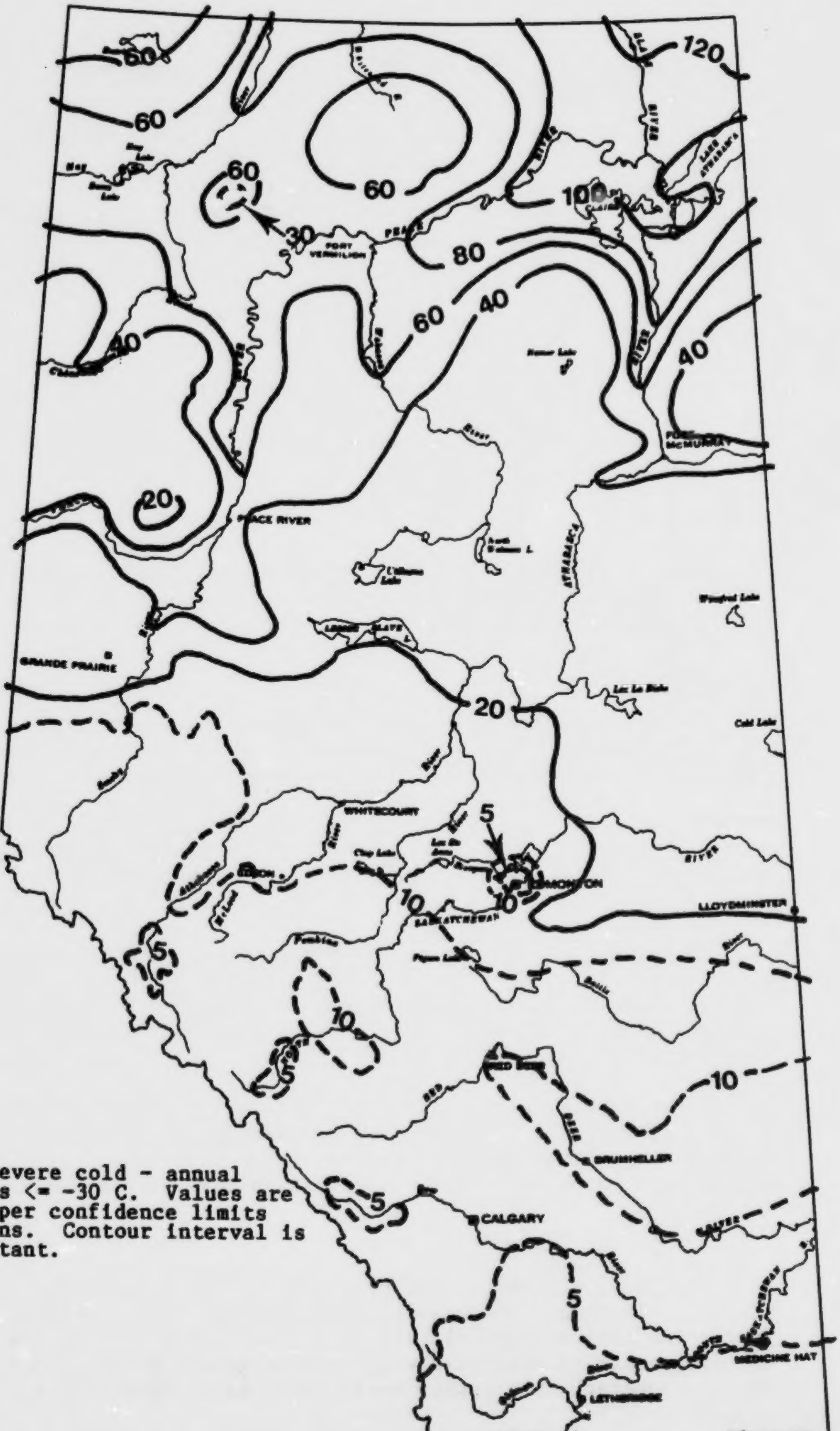
Temperatures in the southern third of the province rarely fall below -30 C (Figure 1). The extremely cold air masses that move into the province do not often migrate to the southern regions. Also, the main valleys of the cordillera area do not experience much severe cold. For example, Jasper, Lake Louise, Barrier Lake, and Crowsnest Pass regions have few occurrences of severe cold. Their elevations, the Front Range barriers, and the relative proximity of the Pacific Ocean account for this.

There is a very strong gradient along the Athabasca River in northeastern Alberta. Fort McMurray A, Fort Chipwyan A, and Fort Smith A average 38.8, 81.1, and 121.1 degree days below -30 C, respectively. The mean position of the arctic air mass is important in this, as elevation differences are minimal.

In the north, elevation is an important climatic control in terms of the distribution of extremely low temperatures. For example, Mount Watt is generally within the warm sector of the inversion. It averages 24.1 degree days below -30 C while nearby High Level A has a mean of 75.3.

4.2 Annual Snow on Ground

Latitude, elevation, and proximity to the continental divide are the primary climatic controls in determining this variable (Figure 2). Increasing latitude and elevation, and being closer to the continental divide, result in more days with snow on ground greater than or equal to 30 cm. However, rain shadow areas (such as at Jasper), or the dynamics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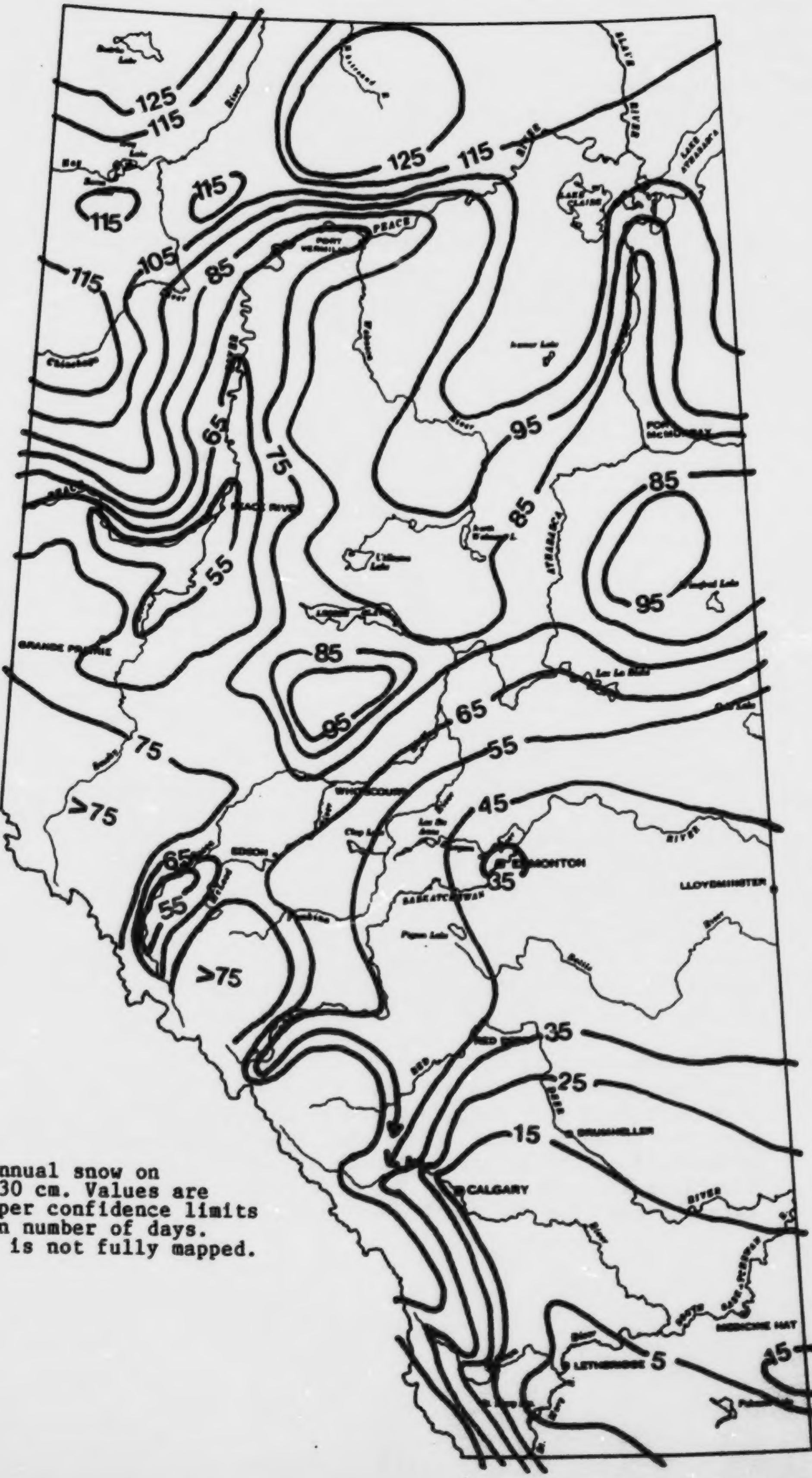
FORT McMURRAY
PEACE RIVER
GRANDE PRAIRIE
LESSER SLAVE L.
WHITECOURT
EDSON
EDMONTON
LLOYDMINSTER
SASKATCHEWAN
RED DEER
DRUMHELLER
CALGARY
MEDICINE HAT
LETHBRIDGE
ATHABASCA
RIVER
Lac La Biche
Cold Lake
Pigeon Lake

Figure 1: Severe cold - annual degree days <= -30 C. Values are the 90% upper confidence limits of the means. Contour interval is not consistant.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PEACE
FORT VERMILION
LAKE CLAIRE
LAKE ATHABASCA
FORT McMURRAY
PEACE RIVER
ATHABASCA
GRANDE PRAIRIE
Lac La Biche
WHITECOURT
EDSON
EDMONTON
SASKATCHEWAN
LLOYDMINSTER
RED DEER
DRUMHELLER
CALGARY
MEDICINE HAT
LETHBRIDGE

Figure 2: Annual snow on ground >= 30 cm. Values are the 90% upper confidence limits of the mean number of days. Cordillera is not fully mapped.

of chinook winds in the lee of the mountains (see Pincher Creek vis-a-vis Lethbridge A) present anomalies to the distributions.

4.3 Mild Days in Winter

Areas that are near the continental divide and have relatively low elevations have the most number of days with maximum temperatures above 5 C (Figure 3). For example, the 10-day isopleth goes from Oyen, in the southeast, to High Level A, which is in the far northeast. At the other extreme, Lethbridge A has more than 45 days above 5 C while Fort Smith A has less than 2.

4.4 Length of Winter

The areal nature of this variable is small when compared to those discussed above (Figure 4). In the non-mountainous areas of the province the measured range in the length of winter is from 190 days at Milk River to 227 at Fort Smith A. The length of winter at the mountain sites are 240 days at Lake Louise and 262 at Columbia Icefields.

The reasons for this pattern are the general increase in elevation from north to south, greater water vapor content of the northern air, and the lack of cloud cover in the south compared to the north. The mountain stations have significantly greater lengths of winter primarily due to the effects of adiabatic drainage.

4.5 Winter Severity Index

The WSI is a synthesis of the four climatic variables discussed above (Figure 5). More emphasis has been placed on the very cold and mild winter days than on the length of winter and annual snow on ground. The resulting map gradients generally correspond to latitude and elevation, but there are exceptions.

In the non-cordilleran regions the WSI isopleths are oriented from the eastsoutheast to the westnorthwest. This is consistent with many of Alberta's winter climatic patterns and represents the overall ameliorating effects due to the maritime influence.

The relatively mild winter climates of the main valleys of the mountainous regions are evident in the areal nature of the WSI. These areas are unique in that they are relatively near the Pacific Ocean and they are often protected from incursions of cold arctic air by the Front Ranges and by their high elevations which puts them into the warm inversion air. They rarely have deep snow covers because they are in rain shadows from the Pacific and up-slope air.

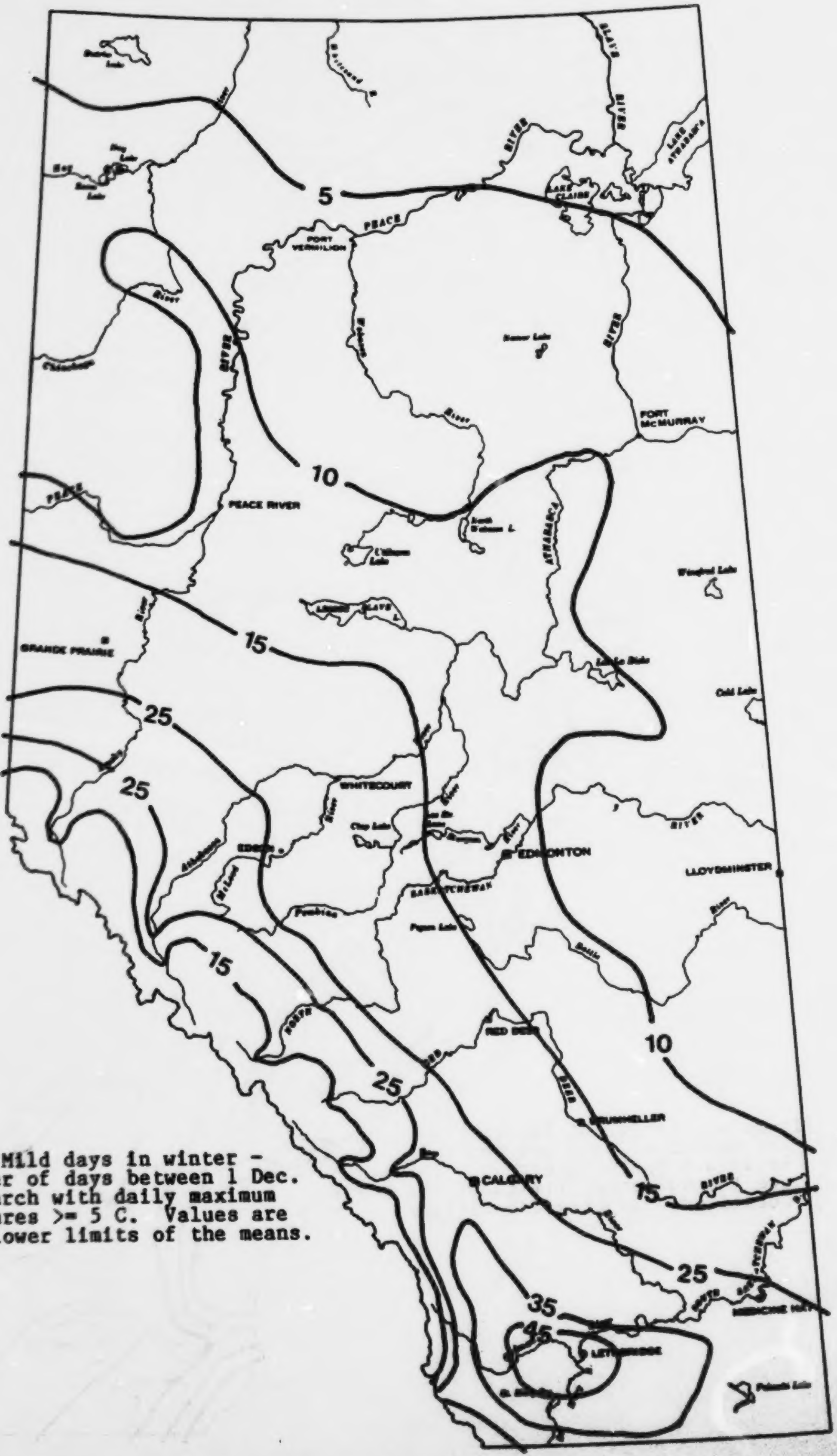
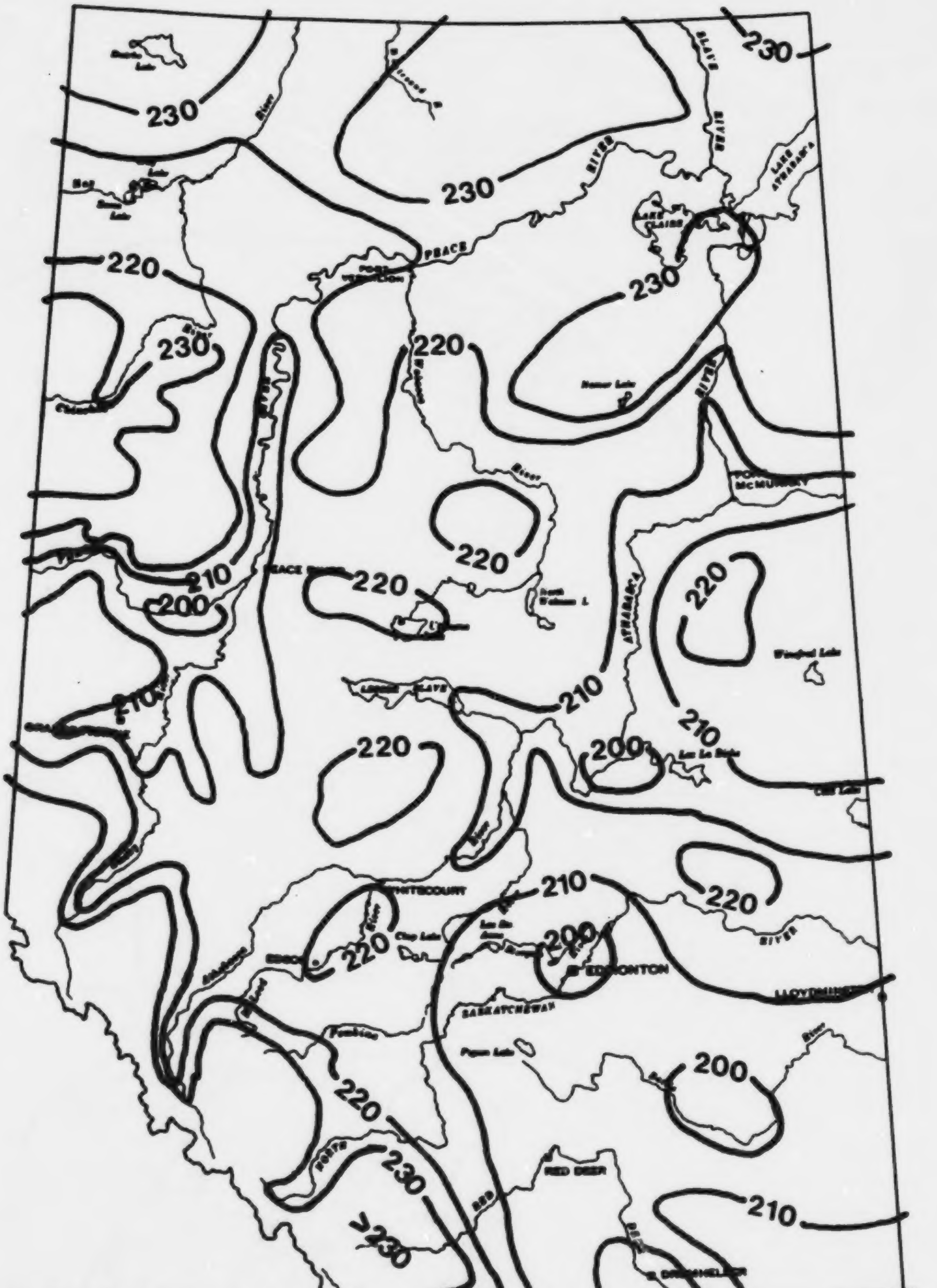

SLAVE RIVER
LAKE ATHABASCA
LAKE CLAIRE
5
PEACE
FORT VERMILION
RIVER
FORT McMURRAY
10
PEACE RIVER
ATHABASCA
15
GRANDE PRAIRIE
25
25
WHITECOURT
EDSON
EDMONTON
LLOYDMINSTER
SASKATCHEWAN
15
RED DEER
10
25
DRUMHELLER
CALGARY
15
25
35
45
MEDICINE HAT
LETHBRIDGE

Figure 3: Mild days in winter - the number of days between 1 Dec. and 31 March with daily maximum temperatures >= 5 C. Values are the 90% lower limits of the means.


230
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200
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200
220
230
>230
210
200
200
210
PEACE
SLAVE RIVER
LAKE ATHABASCA
LAKE CLAIRE
FORT McMURRAY
ATHABASCA
PEACE RIVER
LESSER SLAVE
Lac La Biche
Cold Lake
WHITECOURT
EDSON
EDMONTON
LLOYDMINSTER
SASKATCHEWAN
Pigeon Lake
RED DEER
DRUMHELLER
CALGARY
MEDICINE HAT
LETHBRIDGE

Figure 4: Length of winter - the number of days between fall lysis and spring green-up. Values are the 90% upper limits of the means. Cordilleran mapping incomplete.

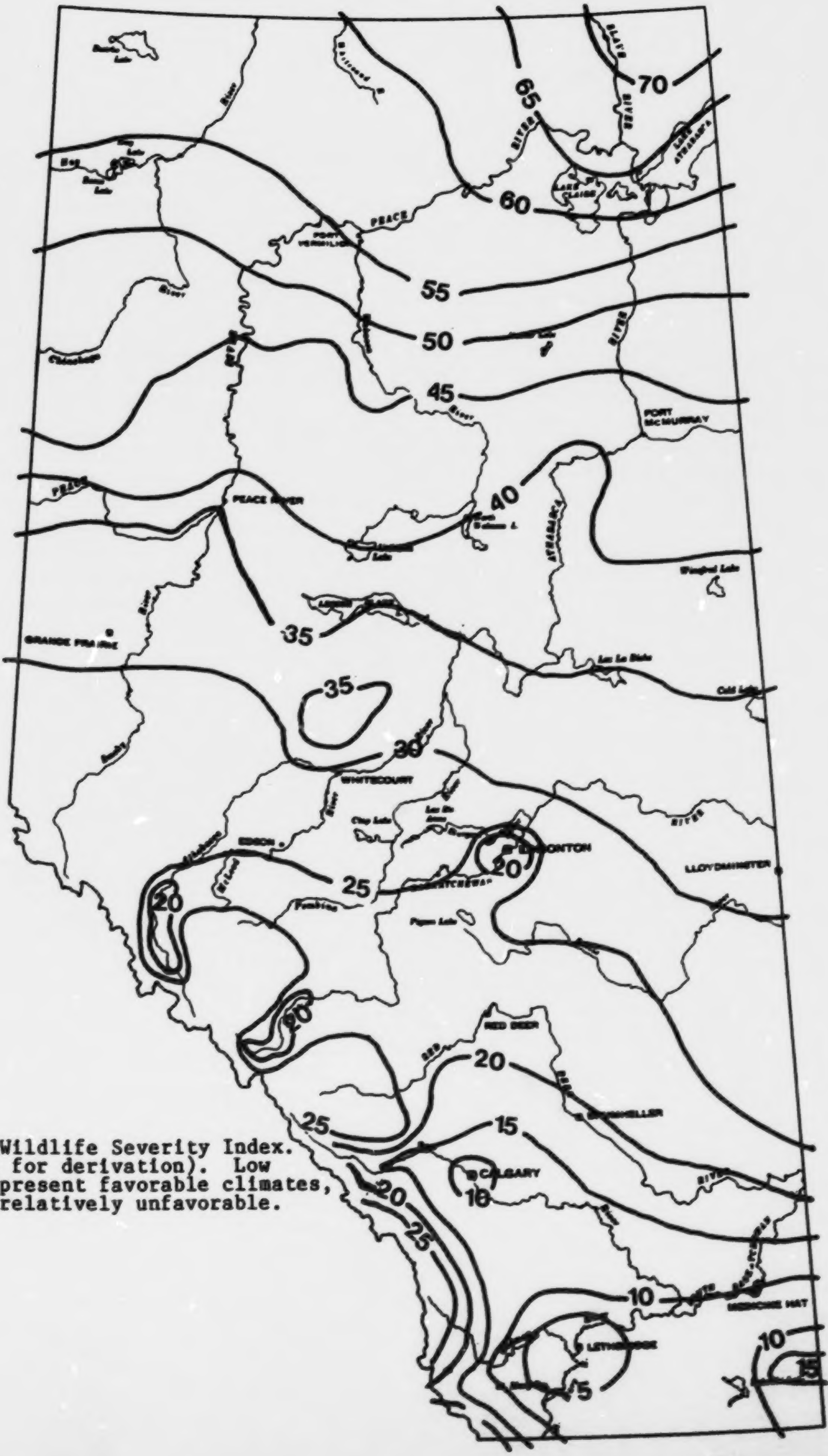
70
65
60
55
50
45
40
35
35
30
25
20
20
20
25
20
15
10
20
25
10
10
15
5
SLAVE RIVER
LAKE ATHABASCA
LAKE CLAIRE
PEACE
FORT VERMILION
FORT McMURRAY
PEACE RIVER
ATHABASCA
GRANDE PRAIRIE
Lac La Biche
Cold Lake
WHITECOURT
EDSON
Chip Lake
EDMONTON
LLOYDMINSTER
Pembina
Pigeon Lake
RED DEER
DRUMHELLER
CALGARY
MEDICINE HAT
LETHBRIDGE

Figure 5: Wildlife Severity Index. (See text for derivation). Low values represent favorable climates, high are relatively unfavorable.

5. CONCLUSIONS

Thirty-year periods from 123 climate stations in Alberta and adjacent sites in British Columbia, Saskatchewan, and Northwest Territories have been reduced and synthesized. The data from locations with less than 30-year records have been normalized. Much of the province has adequate records for meaningful results. However, limited data are available for the northern Rocky Mountains and north-central Alberta. The result is that the climate extrapolations are not as reliable in these regions.

During winter in Alberta the climatic elements do not reflect latitudinal gradients. Other climate influences outweigh the effects - the cordilleran regions separating the Pacific Ocean from the Great Plains, the general rise in elevation from north to south, rain shadow effects, and the average position of the actic front. These controls result in a seemingly anomalous distribution of climates. For example, the 10-day isopleth of the number of winter days with a maximum temperature of 5 C or more extends from near the southeastern corner of the province to the north end of the Peace River district - a north-south distance of 900 km. Yet, on the relatively featureless short-grass prairie region, there is more than a 35-day difference between Lethbridge and Sibbald - a distance of only 230 km.

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A CLIMATOLOGY FOR FORECASTING AT THE ALBERTA WEATHER CENTRE

by
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Alberta Weather Centre
May 13, 1985

ABSTRACT

A series of climatological tables for the synoptic stations in the Alberta Weather Centre (ALWC) area of responsibility has been developed using the resources of the Canadian Climate Centre (CCC). The results are being used in support of the forecast programs.

INTRODUCTION

The value of climatology as an input in the forecasting process has long been recognized. Nevertheless, its use has been limited by the difficulty of extracting and displaying the many different parameters available. This paper describes the climatological data prepared and used in the Alberta Weather Centre's forecasting program.

METHOD

Access to the Canadian Climate Centre's archives and processing capabilities has made it relatively simple for individuals in the field to process specific data according to their needs. The ALWC decided therefore, to acquire as much climate data as would be useful and to display it in as clear a manner as possible.

Five main data types were considered and used in this program:

a) mean hourly values
b) wind data
c) diurnal frequencies
d) event durations
e) ceiling/visibility probabilities

The mean hourly values for each month were calculated using the CCC's General Report Program (GRP) 103. The weather elements considered were:

a) temperature
b) dew point
c) relative humidity
d) cloud amount
e) mean sea level pressure

The data were examined and after consideration the Mean Hourly Cloud Amount and the Pressure data were not included in the final displays.

The wind data were collected using the CCC "Model B" analysis. First, the winds were sorted into the 16 points of the compass, then the mean speed and the frequency of occurrence for each direction were calculated.

The diurnal frequencies and durations of different weather conditions were collected using GRPs 107 and 108. The duration events were sorted into 17 groups:

a) 12 with 1-hour lengths covering the period from 1 to 12 hours each,

b) four with 3-hour lengths covering the period from 13 to 24 hours, and

c) one for durations of 25 hours or more.

The duration program sorts weather events according to the lengths of their duration. For example, if it rains at 12Z and at 13Z, then it is considered to be one rain event with a duration of two hours. If it rains as 12Z, 13Z, 14Z, 15Z, not at 16Z, and then again at 17Z and 18Z, we have the option of deciding whether to call this one rain event of six hours with a "drop-out" or break of one hours, or whether to consider it as two separate rain events of four and two hours respectively. "Drop-outs" of different lengths were tried, and it was decided to use a zero hour drop-out, i.e. our second example is to be considered as two separate rain events of four and two hours respectively.

GRPs 107 and 108 were run with 24 identifically defined weather conditions which are listed in Appendix 2. All the data were processed on the AS6 at the CCC in Toronto, and the results written onto tape. The tapes were sent to the ALWC where the regional mini-computer was used to re-format and merge the various tables. Several programs were used to convert the data from MKS units to imperial where appropriate. Finally, the data were normalized to a 20-year period. The normalization was necessary because several stations had quite a few missing observations at night. One additional benefit of the normalization was that stations could be directly compared with each other.

The last climate program used was C1034 which produces tables of ceiling and visibility probabilities as a function of wind velocity, weather type and season. This program sorts and stores the data into a buffer then produces the tables of output. For our purposes, a copy of the program was modified to output the buffer only onto tape. Two programs were written to re-format the output for paper and for display on the forecaster's CRT. At the present time, however, storage considerations have delayed the implementation of the CRT display program.

Program C1034 has been described elsewhere (Purves, 1975), but the definitions of the weather categories are reproduced here for convenience. The weather classes are:

a) Nil (Nil or Thunder)
b) Fog (Fog, Smoke, Haze, Drizzle, IF, and/or IC
c) Rain (Rain, Rain Showers or Hail), and
d) Snow (all frozen precipitation except Hail)

These weather classes are in order of increasing rank, and if two or more types occur simultaneously, then the one of the highest rank is chosen. Blowing Snow is ignored, but if it occurs by itself, the observation is skipped completely.

RESULTS

The data are stored in binders. One binder contains all the duration and diurnal statistics for the group of stations for a given month. The stations are listed as they appear in the list of FTs produced by the office. Each station has two pages of output, the first showing the duration statistics, the second showing the diurnal frequencies and means. At the end of the binder, summaries of the more important weather elements are included, with the data for all stations on one page. In this way, should thunderstorms be the significant weather feature, only one page of data need be consulted. Examples are shown in Tables 1 to 3. Additional binders contain the ceiling and visibility statistics group by season. The format of the two different page types is shown in Tables 4 and 5.

All the various data are stored on tape, and several transfer files allow the printing of the data in a variety of formats.

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Ceiling Probabilities EDMONTON INTNL Wind Direction 012 - 033

Wind Speed	1 - 9				10 - 19				20+ Knots			
Group	1	2	3	4	1	2	3	4	1	2	3	4
Nil		1	2	5			3	17				
Fog	10	9	6	11		33	33	33				
Rain												
Snow		4	9	32		3	11	48			33	67
Visibility Probablities												
Fog	10	1	20	31				33				
Rain												
Snow		4	31	28	1	12	38	23		33	33	33
	NIL	FOG	RA	SN	NIL	FOG	RA	SN	NIL	FOG	RA	SN
Samples	242	105	2	447	30	3		170				3
Prob.	30	13	0	56	13	1	0	85	0	0	0	100

Ceiling Probabilities Wind Direction 034 - 056

Nil		1	1	3			4	7				
Fog	10	14	5	6		29		14				
Rain												
Snow	1	3	6	33		1	13	48			100	
Visibility Probablities												
Fog	10	6	25	25			43	29				
Rain												
Snow		2	31	26		13	39	18				
	NIL	FOG	RA	SN	NIL	FOG	RA	SN	NIL	FOG	RA	SN
Samples	208	63	1	318	23	7		89	1			1
Prob.	35	11	0	54	19	6	0	75	50	0	0	50

Ceiling Probabilities Wind Direction 057 - 078

Nil		1	4	7								
Fog	13	15	5	8			25	75				
Rain			33	67								
Snow	1	3	13	40			31	41				
Visibility Probablities												
Fog	23	8	15	23			25					
Rain												
Snow		4	36	25		13	42	21				
	NIL	FOG	RA	SN	NIL	FOG	RA	SN	NIL	FOG	RA	SN
Samples	152	40	3	236	5	4		71				
Prob.	35	9	1	55	6	5	0	89	0	0	0	0

Ceiling Probabilities Wind Direction 079 - 101

Nil		1	2	6			5	10			100	
Fog	8	10	3	8	3	7	3	45				
Rain					100							
Snow		3	10	31		2	14	50			100	
Visibility Probablities												
Fog	8	6	11	30	3		7	7				
Rain						100						
Snow		5	29	23		6	45	27	20	20	20	
	NIL	FOG	RA	SN	NIL	FOG	RA	SN	NIL	FOG	RA	SN
Samples	376	89	1	414	58	29	1	238	1			5
Prob.	43	10	0	47	18	9	0	73	17	0	0	83

Ceiling Groups	(000 - 100)	(200 - 400)	(500 - 900)	(1000 - 2400)
Visibility Groups	(0 - 3/8)	(1/2 - 3/4)	(1 - 21/2)	(3 - 5)

Dec, Jan, Feb

Table 4

Ceiling Probabilities EDMONTON INTNL Table

Group	1	2	3	4
Nil				3
Fog	9	9	4	2
Rain				38
Snow				3
Visibility Probabilities				
Fog	13	7	20	22
Rain				15
Snow				

	NIL	FOG	RA	SN
Samples	2653	781	13	730
Prob.	64	19	0	17

Ceiling Groups (000 - 100) (200 - 400) (500 - 900) (1000 - 2400)
Visibility Groups (0 - 3/8) (1/2 - 3/4) (1 - 21/2) (3 - 5)

Dec. Jan. Feb

Probability of Weather Type As a Function of Wind Velocity

Wind Speed	1 - 9				10 - 19				20+ Knots			
Wx Type	N	F	R	S	N	F	R	S	N	F	R	S
NNE	30	13		56	13	1		85				100
NE	35	11		54	19	6		75	50			50
ENE	35	9	1	55	6	5		89				
E	43	10		47	18	7		73	17			83
ESE	60	11		29	40	10		50	16			84
SE	74	10		16	65	6		29	58	3		39
SSE	82	8		10	80	6		14	66			34
S	88	7		5	95	1		4	100			
SSW	88	7	1	4	95			5	100			
SW	90	4	1	4	98			2				
WSW	89	4	1	6	74	1	3	3				
W	83	6	1	11	72	1	1	6	33			67
WNW	70	8		21	79	4	1	16	82		2	17
NW	53	10	1	37	54	3		42	56	1	1	42
NNW	42	10	1	48	31	4		65	29	2	1	68
N	37	14		49	26	4		71	19			81
Calm	64	19		17								

Wind Frequency Table

Wind Speed	1 - 9	10 - 19	20+ Knots
NNE	2		
NE	1		
ENE	1		
E	2	1	
ESE	3	2	
SE	5	5	
SSE	5	3	
S	11	3	
SSW	6		
SW	4		
WSW	4	1	
W	6	2	
WNW	4	3	
NW	3	3	
NNW	2	2	
N	3	2	
Calm	9		

Table 5

DIURNAL FREQUENCY OF
THUNDERSTORMS

MONTH JUL — HOUR U.T.C.

STN	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	00	01	02	03	04	05	06	TOTAL
YEG	14	17	12	10	7	3	4	4	10	4	3	4	4	4	8	11	22	31	26	31	27	33	17	17	[illegible]
YYC	8	6	8	4	2	3	3	1	1	1	1	1	6	8	14	19	20	32	21	16	17	21	17	17	250
YXD	7	10	8	7	6	5	5	2	5	3	1	1	3	5	7	10	14	19	17	16	21	17	12	11	214
YLL	15	11	9	10	5	4	7	3	2	4	5	5	5	6	5	7	7	11	12	15	17	17	20	15	222
YQF	12	10	8	6	3	5	6	4	1	3	2	1	4	3	6	12	20	20	21	19	21	22	23	17	259
YQL	12	8	5	4	3	2	4	5	4	3	1	3	3	5	6	12	14	16	19	16	17	17	14	12	205
YXH	10	12	11	3	5	4	5	4	1	2	3	4	3	3	6	3	7	5	15	12	13	14	15	14	151
YQU	10	6	5	5	3	3	2	5	4	1	2	1	2	8	9	15	13	17	18	22	15	14	13	15	212
YXJ	11	10	7	4	1	1	3	5	3	1		1	2	5	8	13	20	19	13	20	18	14	14	17	233
YPE	7	3	3	2	3	2	2	4			3	2	7	9	12	17	21	17	18	17	15	12	13	7	[illegible]
YYE	12	7	6	5	4	3	1	1	2	1	2	1	3	10	16	19	23	29	31	23	24	25	20	18	[illegible]
YOJ	4	3	3	4	4	2	1	2	1	1	2	2	4	7	7	12	16	23	18	22	15	13	12	10	[illegible]
YZH	14	10	8	6	6	5	4	7	4	4	2	5	9	19	11	16	21	23	16	21	19	19	19	16	282
YMM	10	11	10	9	6	5	5	4	3	3	3	5	10	17	25	30	30	34	26	30	33	33	17	16	357
YCT	23	19	15	14	11	6	6	6	5	5	3	3	5	9	10	12	17	19	25	35	36	22	22	25	334
YRM	6	5	8	1	2	3	1	1	2	1	3	4	6	14	32	38	37	40	26	24	32	33	11	18	336
WBA		4				1	2		2	1	2	2	5	7	5	7	7	9	8	10	6	4	8	5	94
WJA						1			1		1	1	2	5	5	1	5	4	8	7	3	2	2	4	51
YET	5	5	8	9	3	10	5	3	5	2	2	2	6	13	19	27	27	43	32	27	22	19	30	13	335
YZU	10	6	6	5	5	3	5	3	3	4	3	4	8	10	15	23	27	31	23	30	25	22	19	19	312
YED	11	10	9	6	8	4	4	4	4	3	1	1	1	3	9	10	14	25	20	20	26	22	15	16	246
YOD	19	15	15	10	10	6	4	3	3	1	3	3	3	9	10	12	14	19	15	21	16	17	18	17	264
YPY	6	5		3	6	5	1	4	1	1		1	4	5	8	12	10	17	18	6	10	3	5	10	150
STN	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	00	01	02	03	04	05	06	TOTAL

DURATIONS OF
THUNDERSTORMS

JULY — NUMBER OF SPECIFIED DURATION LENGTHS

	1 TO 1	2 TO 2	3 TO 3	4 TO 4	5 TO 5	6 TO 6	7 TO 7	8 TO 8	9 TO 9	10 TO 10	11 TO 11	12 TO 12	13 TO 15	16 TO 18	19 TO 21	22 TO 24	25 TO 9999	NUMBER OF DUR EVENTS	LONGEST DURATION
YEG	101	34	23	13	4	2	1											176	7
YYC	95	42	14	3	1		1			1								156	10
YXD	85	38	10	5	1													139	5
YLL	63	35	15	5	3	1		1										122	8
YQF	38	34	18	7	1	2		1										150	8
YQL	61	30	17	3	2	1												115	6
YXH	67	30	9	1	2	1	1											111	7
YQU	57	32	12	5	3	2	1											113	7
YXJ	55	32	12	4	2	3	1											108	7
YPE	73	29	12	5	2													121	5
YYE	84	40	21	7	3	1		1										157	8
YOJ	64	24	14	7	1													110	5
YZH	33	29	18	7	7	2		2										147	8
YMM	85	41	23	13	6	3	1	1			1							174	11
YCT	82	52	28	10	4													175	5
YRM	116	49	20	10	5			1										201	8
WBA	64	10	5															79	3
WJA	39	3	1		1													45	5
YET	124	57	13	8		2					2							205	11
YZU	103	45	25	4	3	1			1									182	9
YED	79	45	11	8	1	1	1											145	7
YOD	78	40	20	6	2	1	1											148	7
YPY	51	22	11	3	3													89	5

Normalized - 20 Years

Table 3

EDMONTON INT'L A

MONTH MAY HOUR U.T.C.

COND	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	00	01	02	03	04	05	06	TOTAL
T	1	3	1	2	1		1		1			3		3	3	4	7	4	6	2	4	4	4	5	56
RW	28	23	18	16	18	19	16	18	19	26	28	29	26	31	37	32	39	32	44	30	46	31	26	29	660
R	27	29	35	27	29	26	25	24	25	28	28	23	23	20	18	18	19	19	17	21	18	25	26	26	576
L	1	2	2	3	4	4	2	4	4	6	4	4	1	4	4	3	2	3	3	4	5	4	3	2	74
ZR																									0
ZL																									1
ZP																									0
SW	1	1		1	4	3	3	2	1	1	2	3	1	2	1	4		2	2	4			1	2	37
S	6	5	6	6	6	7	9	9	10	8	9	11	10	5	4	4	4	4	4	4	4	4	5	6	146
F	2	4	5	7	13	12	19	13	11	5	3	1	2	1	4	4	2	1	1	2	1	.	2	1	115
	VISIBILITY IN RANGE SHOWN WITH FOG																								
0-.5			3	3	7	7	9	4	2																34
.6-1	1				1	2	3	2	2				1												11
1.-2	1	1	2	3	1	2	2	1	3	1	1	1	1			1	1	1	1	1	1	1	1	1	26
2.-3	1	2			1	1	4	4	1	3					1	1	1	1		2					21
ICIF																									0
BLZD																									0
BS																									0
	CEILINGS AND/OR VISIBILITIES LESS THAN LIMITS SHOWN																								
2/.5			3	3	6	5	8	4		1															29
5/1	3	4	9	10	16	17	14	10	9	7	4	2	2	1	2	1	3		2	2	2	1	4	3	122
8/2	9	9	13	19	21	30	25	22	19	17	13	11	10	8	7	10	10	9	7	7	9	7	8	8	307
10/3	14	13	18	23	25	33	33	33	27	22	18	18	18	15	13	11	12	14	12	12	11	10	10	13	428
25/5	31	33	32	35	44	55	55	55	59	56	56	55	43	40	34	33	27	33	28	33	26	24	23	27	936
TT	7	6	6	5	5	4	6	8	10	11	12	13	14	15	15	16	16	15	15	14	12	10	9	8	17/ 3
TD	1	1	1	1	1	1	1	2	2	2	2	1	1	1	1	1	1	1	1	1	2	2	2	2	
RH	69	71	73	75	77	78	76	69	63	56	51	48	45	43	42	41	41	42	44	47	53	60	64	67	
WSPD	7	7	7	6	6	7	7	8	9	9	10	10	11	11	11	10	10	10	10	9	8	7	7	7	
W15	32	33	30	26	26	29	33	51	74	90	104	113	135	131	135	116	124	121	99	77	50	33	40	46	1743
W30	2	1						1	2	4	4	4	4	4	3	2	3	2	1	1	3	1	2	2	41

DIRECTION	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	N	CALM
FREQ	3	2	3	5	7	10	9	8	3	3	3	8	8	9	7	7	5
MSPD	8	7	7	8	10	10	10	8	6	5	6	3	11	11	10	9	

Normalized - 20 Years

Table 2

EDMONTON INT'L A Normalized - 20 Years

MAY NUMBER OF SPECIFIED DURATION LENGTHS

	1 TO 1	2 TO 2	3 TO 3	4 TO 4	5 TO 5	6 TO 6	7 TO 7	8 TO 8	9 TO 9	10 TO 10	11 TO 11	12 TO 12	13 TO 15	16 TO 18	19 TO 21	22 TO 24	25 TO 9999	NUMBER OF DUR EVENTS	LONGEST DURATION
T	31	8	1	2														41	4
RW	227	72	33	13	11	1	4	2	1		1		2					366	15
R	59	26	13	7	9	4	5	3	2		3	2	5	1	2		3	142	36
L	11	7	4	1		1	2	1	1									27	7
ZR																		0	0
ZL																		0	0
ZP																		0	0
SW	15	4	1		1		1											22	7
S	4	3	3		2	2			1		2	1	1	1		1	1	20	36
F	18	5	7	5	3	2	1	1	1									42	[illegible]

VISIBILITY IN RANGE SHOWN WITH FOG

	1 TO 1	2 TO 2	3 TO 3	4 TO 4	5 TO 5	6 TO 6	7 TO 7	8 TO 8	9 TO 9	10 TO 10	11 TO 11	12 TO 12	13 TO 15	16 TO 18	19 TO 21	22 TO 24	25 TO 9999	NUMBER OF DUR EVENTS	LONGEST DURATION
0-.5	5	1	4	4														14	4
.6-1	9	1																10	2
1.-2	11	2	1	1	1													16	5
2.-3	19	1																20	2
ICIF																		0	0
BLZD																		0	0
BS																		0	0

CEILINGS AND/OR VISIBILITIES LESS THAN LIMITS SHOWN

	1 TO 1	2 TO 2	3 TO 3	4 TO 4	5 TO 5	6 TO 6	7 TO 7	8 TO 8	9 TO 9	10 TO 10	11 TO 11	12 TO 12	13 TO 15	16 TO 18	19 TO 21	22 TO 24	25 TO 9999	NUMBER OF DUR EVENTS	LONGEST DURATION
2/.5	7	2	3	3														14	4
5/1	22	8	6	4	3	2	2							1				47	13
8/2	38	13	11	4	4	4	3	2	1	2	2	1		3			1	86	25
10/3	37	20	11	8	8	7	4	1	1	1	3			3	1	1	1	106	49
25/5	57	33	20	18	13	8	4	2	4	4	1	2	4	4	1	2	5	182	[illegible]
W15	302	77	35	30	21	16	12	12	10	7	5	3	10	10	3		3	554	33
W30	11	4	1	1		1	2											16	7

Table 1

Appendix 1

Station Data

Station Name	CCC Station Number	Period of Record	Number of Years
Banff	3050520	1953 - 1982	30
Calgary Intnl A	3031093	1953 - 1982	30
Cold Lake A	3081680	1954 - 1982	29
Coronation	3011880	1953 - 1982	30
Edmonton Intnl A	3012205	1961 - 1982	22
Edmonton Muni A	3012208	1953 - 1982	30
Edmonton Namao A	3012210	1955 - 1982	28
Edson A	3062244	1970 - 1982	13
Fort Chipewyan A	3072658	1967 - 1982	16
Fort McMurray A	3062693	1953 - 1982	30
Fort Nelson A	1192940	1953 - 1982	30
Fort St. John A	1183000	1953 - 1982	30
Grande Prairie A	3072920	1953 - 1982	30
High Level	3073145	1967 - 1970	4*
High Level A	3073146	1976 - 1982	7*
Jasper A	3053520	1953 - 1982	30
Lethbridge A	3033880	1953 - 1982	30
Medicine Hat A	3034480	1953 - 1982	30
Peace River A	3075040	1953 - 1982	30
Red Deer A	3025480	1953 - 1982	30
Rocky Mtn	3015520	1953 - 1977	25*
Rocky Mtn A	3015520	1978 - 1982	5*
Slave Lake A	3066001	1971 - 1982	12
Vermilion	3016800	1953 - 1982	30
Whitecourt	3067370	1953 - 1977	25*
Whitecourt A	3067372	1978 - 1982	5*

*Stations that had their data sets merged.

Appendix 2

Weather Conditions

Abbreviation	Definition
T	Thunderstorm
RW	Rain Showers
R	Rain
L	Drizzle
ZR	Freezing Rain
ZL	Freezing Drizzle
ZP	Freezing Precipitation (ZR and/or ZL)
SW	Flurries
S	Snow
F	Fog with no R, RW, L, or ZP
0-.5	Visibility 0-1/2 mi in fog with no R, L, or ZP
.6-1	Visibility 5/8-1 mi in fog with no R, L, or ZP
1.-2	Visibility 11/4-2 in fog with no R, L, or ZP
2.-3	Visibility 21/4-3 in fog with no R, L, or ZP
ICIF	Ice Crystals and/or Ice Fog
BLZD	Snow and/or Blowing Snow with temperature less than zero, winds of 41 km/h or more and a visibility of 1 km or less.
BS	Blowing Snow
2/.5	Ceilings less than 200 feet and/or visibilities less than 1/2 mi
5/1	Ceilings less than 500 and/or vis. less than 1
8/2	Ceilings less than 800 and/or vis. less than 2
10/3	Ceilings less than 1000 and/or vis. less than 3
25/5	Ceilings less than 2500 and /or vis. less than 5
TT	Mean Temperature (degrees C)
TD	Mean Dew Point (degrees C)
RH	Mean Relative Humidity (%)
WSPD	Mean Wind Speed (knots)
W15	Wind greater than 15 knots
W30	Wind greater than 30 knots
FREQ	Frequency of occurrence of given wind direction (%)
MSPD	Mean Wind Speed for given direction (knots)

PRECIPITATION PROBABILITY BY SOIL ZONE

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Introduction

Precipitation is of major importance to Alberta. It is the key factor in determining the type of cropping system possible (crop-fallow, flex cropping or annual cropping), the productivity of native range and improved pasture, the level of yield expected and last but not least the level of inputs to be used. Alberta Hail and Crop Insurance has found that the two precipitation-controlled conditions, excess moisture and drought, account for a large part of the crop losses experienced by insured crops. In the Peace River area, for example, over 80% of the losses are accounted for by these two factors as shown by the 1978 to 1982 data in Figure 1 (4).

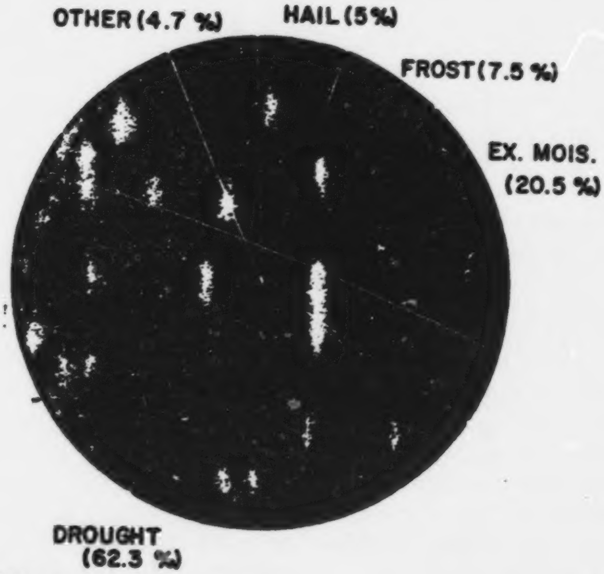


FIGURE 1.

Moisture for crop use comes from stored soil moisture. On dryland, crops can use moisture stored in the soil between growing seasons as well as the growing season precipitation. Under irrigated conditions, supplementally applied water provides a third water source. In both water regimes precipitation occurring on a crop year basis is an important consideration.

Research (8) has shown that specific land (crop) management practices result in reasonably uniform levels of soil storage of non-growing season precipitation. This allows farmers in many areas of the province to decide in early spring, whether to re-crop part of their stubble and how much fertilizer to apply on the land to be cropped. If the year ahead is to be wet, more stubble should be planted and higher levels of fertility should be applied because economic yield responses can be expected. If conditions are to be dry the opposite will be true. This type of decision is based on risk and farmers are normally good risk managers. However, it has been recently evident that professional agrologists, and their technical staff, require some documentation to assist farmers, bank managers, etc. in this risk management.

This project on precipitation probability has been requested formally and informally by several groups within Alberta Agriculture including:

(1) Plant Industry Division (Soil and Feed Testing Laboratory) to provide information to assist farmers in deciding on fertilizer requirements,

(2) Regional Soil Specialist (Region I) to provide information to asssist in promoting recropping of stubble (particularly in dryland salinity areas),

(3) Regional Economist (Region I) to assist in measuring risk associated with various management decisions such as recropping stubble, and

(4) The Irrigation Management Co-ordinator to assist in improving irrigation management projections and in updating precipitation information currently used in farm irrigation system design.

Variability of precipitation has always been present as indicated by changing patterns of settlement such as those experienced in the 1930's. It has only been in the past 20 or 30 years that efforts have been made to quantify this variability. Dey (3) in the 1960's looked at the probability of drought length in days. As part of his study he determined the coefficient of variation for precipitation. Heywood (6) used these coefficients and precipitation means to construct normal distributions of precipitation expections for the individual months of May, June, July, August and the collective May through August period. Testing indicated that individual monthly distributions did not always fit observed data. The collective May through August distribution did fit the observed data. Dupuis (5) has shown similar results for the Lower Peace River area and a number of other stations. Elsewhere, 2 or 3 factor gamma distributions (1) The Markov Chain Model (7,9), as well as 2 or 3 factor Weibull distribution (2) have been used to describe precipitation probability.

These distributions provide a better prediction of probability at the expense of more complex calculation. A concept currently being employed to describe probability is the use of a polynomial equation. Such equations can fit many relationships and lend themselves to computer analysis.

A final approach is to ignore the fitting of a distribution, and use a simple non-distributional ranking process. The values are simply ranked and the probability of occurrence of less than or more than a given value is determined. This type of procedure requires data records of sufficient length to represent the range of conditions expected. It is also impossible to project beyond the existing data limits.

In this paper, this final methodology was used. The major assumption to be accepted is that future precipitation will remain similar to that in the past.

METHODOLOGY

This project and the methodology used has been developed through consultation with the Plant Industry Division of Alberta Agriculture. The periods for which precipitation probabilities are being developed are listed below with the reason for their selection.

PERIOD	REASON
May 1 - July 31	Period in which precipitation is most influential in producing yield in cereals and oilseeds.
May 1 - August 31	Period in which precipitation is most influential in producing yield of forages and pasture.
Sept. 1 - April 30	Non-growing season storage period for most annual crops.
Sept. 1 - Oct. 31	Non-growing season storage of precipitation (mostly rainfall)
Nov. 1 - March 31	Non-growing season storage of precipitation (mostly snowfall)
Sept. 1 - Aug. 31	This crop year is more meaningful for crop production than calendar year.

Selection of time periods by month, weeks or even days is difficult because each crop year is different. In Alberta as a general rule seeding occurs in May, reproductive development occurs in July and maturity is approached in August. This time table occurs in the northern parts of the province as well as the southern part, therefore it provides the best potential classification available. The analysis using the above periods is currently underway. At the time of writing May 1 - July 31, May 1 - Aug. 31 and Sept. 1 to April 30 period have been completed.

In Alberta recommendations on varieties suited for growth and general management practices are made by soil zones. The classification used by the Plant Industry Division (Soil and Feed Testing Laboratory) is being used in this analysis. Meteorology stations with long periods of records (generally 30 years or more) were selected. Occasionally stations with fewer years were used to complete the geographic representation (in these cases 20 years of data were needed). The monthly records were obtained through the courtesy of S. Dupuis of the Climate Appraisal Unit of Energy and Natural Resources.

Data were grouped according to soil test areas (Figure 2) for anlaysis. The intensity of the data used in the analysis is given below:

SOIL TEST AREA	SOIL ZONE	NO. OF STATIONS
1	Brown	10
2	Dark Brown (south Bow River)	7
3	Dark Brown (north Bow River)	8
4	Thin Black (south Bow River)	6
5	Thin Black (north Bow River)	9
6	Black	11
7	Dark Grey and Grey Wooded (Northeast Edmonton)	6
8	Dark Grey and Grey Wooded (Northwest Edmonton)	9
16	Dark Grey Soils of Peace River Region	12
18	Grey Wooded Soils of Peace River Region	
10	Irrigated Soils	

For the purposes of this analysis zones 16 and 18 are lumped. Zone 10 is included within the other zones. (Figure 2).

The quality of data varied somewhat with the station type, the number of station relocations etc. Missing data were filled by regression analysis with adjacent stations.

The data were ranked in ascending order i.e. from the smallest to the largest. The probability of receiving less than a specified level of precipitation was calculated by dividing the number of occurrences up to and including that level of precipitation by the total number of occurrences then multiplying this value by 100.

The probabilities obtained were graphically represented for each station and each soil zone. Based on the appearance of these curves, linear relationships between precipitation and probability were determined.

RESULTS

The relationships between precipitation and probabilities are shown for the Black Soil Zone (Figure 3) for the May 1 to July 31 period. In the Black Soil Zone, the values formed a band. Generally the values in the lowest part of the band comes from stations such as Camrose (at the south edge of the Black Soil Zone) and those in the upper part of the band from areas such as Calmar and Olds which are on the northern or western edges of the soil zone.

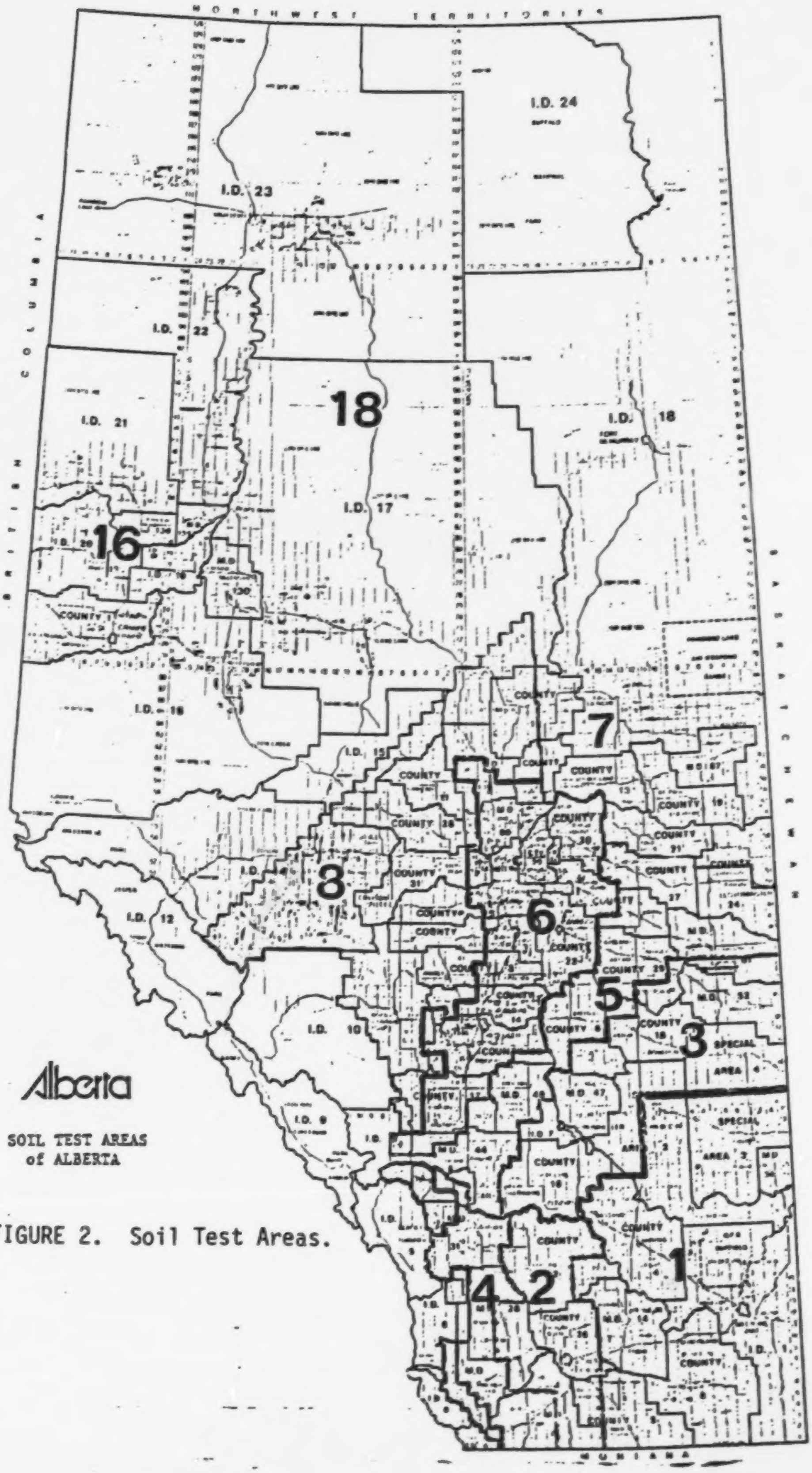
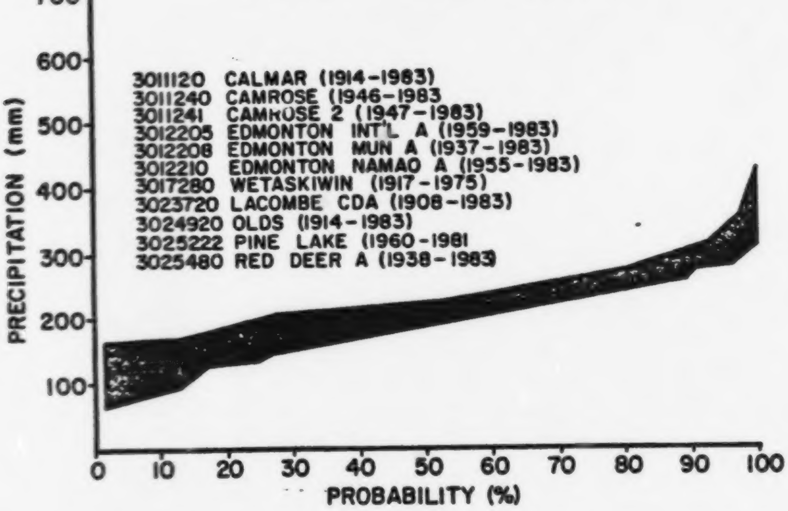

NORTHWEST TERRITORIES
BRITISH COLUMBIA
SASKATCHEWAN
MONTANA
I.D. 24
I.D. 23
I.D. 22
I.D. 21
18
I.D. 18
I.D. 17
16
I.D. 16
I.D. 15
7
8
6
5
3
1
2
4
I.D. 12
I.D. 10
I.D. 9
SPECIAL AREA
Alberta
SOIL TEST AREAS of ALBERTA

FIGURE 2. Soil Test Areas.

FIG. 3 PROBABILITY * OF PRECIPITATION AT 11 STATIONS IN THE BLACK SOIL ZONE.



* Probability of receiving less than indicated amount of precipitation.

Figure 4 shows the relationship between probability and precipitation amounts for the May 1 - July 31 period for 6 stations: Medicine Hat (MH) in the Brown Zone, Lethbridge (Leth) in Dark Brown Zone (south of Bow River), Edmonton (Edm) in the Black Zone and Campsie (Camp) and Elk Point for the Dark Grey zones north west and north east of Edmonton respectively. The changing relationship between probability and precipitation can be seen. In general precipitation increases from the Brown to the Black Soil Zone, from the south to the north and from the east to the west. Data from Peace River is not shown but the relationship between precipitation probability and soil zone does not appear to be as well developed for this geographic region.

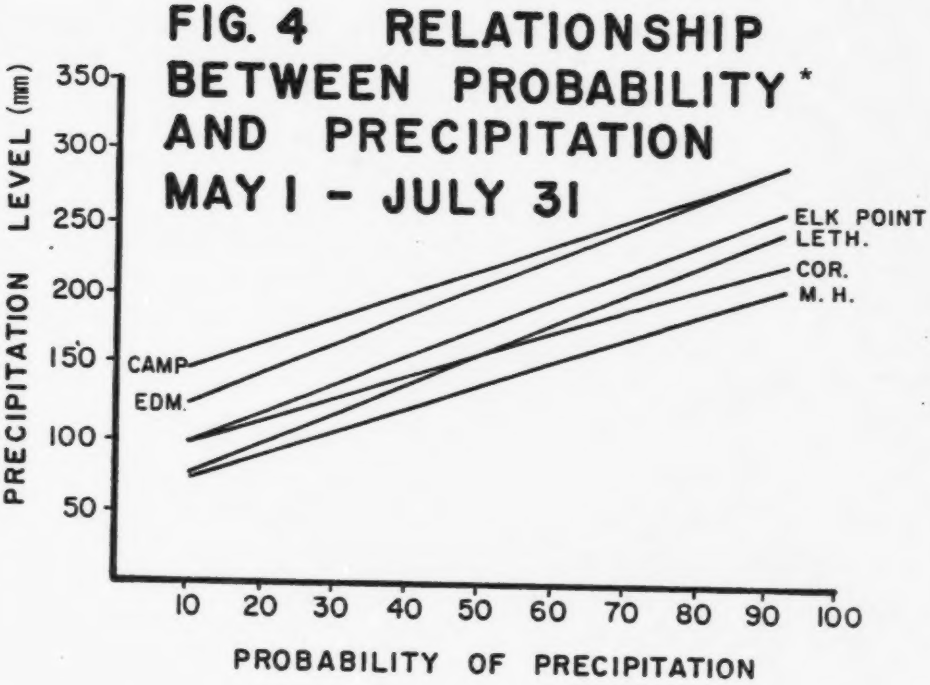


FIG. 4 RELATIONSHIP BETWEEN PROBABILITY* AND PRECIPITATION MAY 1 - JULY 31

* Probability of receiving less than indicated precipitation.

When individual probability relationships are plotted, it is evident that a linear relationship would provide a high degree of fit over a large part of the probability scale. Another example of this straight line relationship is Figure 5 which shows the precipitation for May 1 to July 31 for Medicine Hat. When a straight line is calculated for a probability range of 10 - 90%, it explains over 98% of the variability. To further illustrate a normal distribution of precipitation for Lethbridge (May 1 - July 31) was constructed using a mean precipitation of 166 mm and a standard deviation of ±60 mm (Figure 6). Linear relationships were determined for several probability ranges and their predicted precipitation values were compared to the probabilities determined from actual precipitation (Table I).

FIG. 5 RELATIONSHIP BETWEEN PROBABILITY AND PRECIPITATION (MAY 1 – JULY 31) FOR MEDICINE HAT

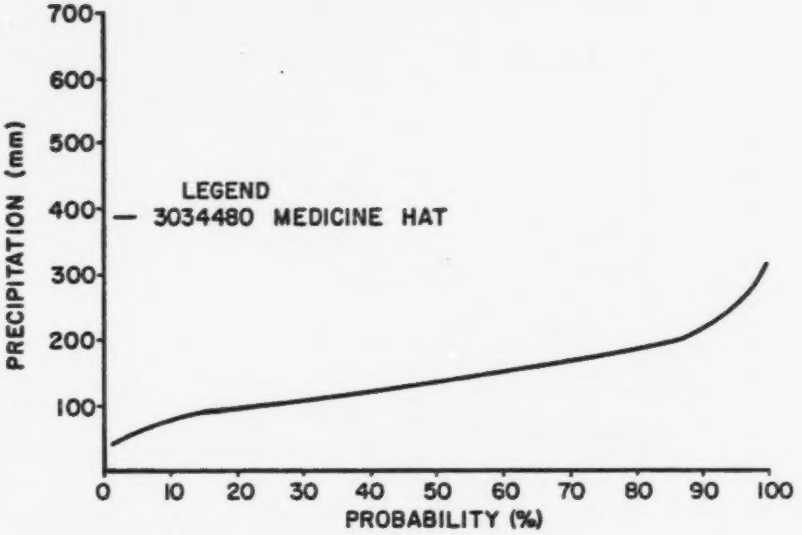


FIG. 6 RELATIONSHIP BETWEEN A NORMAL DISTRIBUTION AND A BEST FIT LINEAR RELATIONSHIP FOR LETHBRIDGE (MAY 1 – JULY 31)

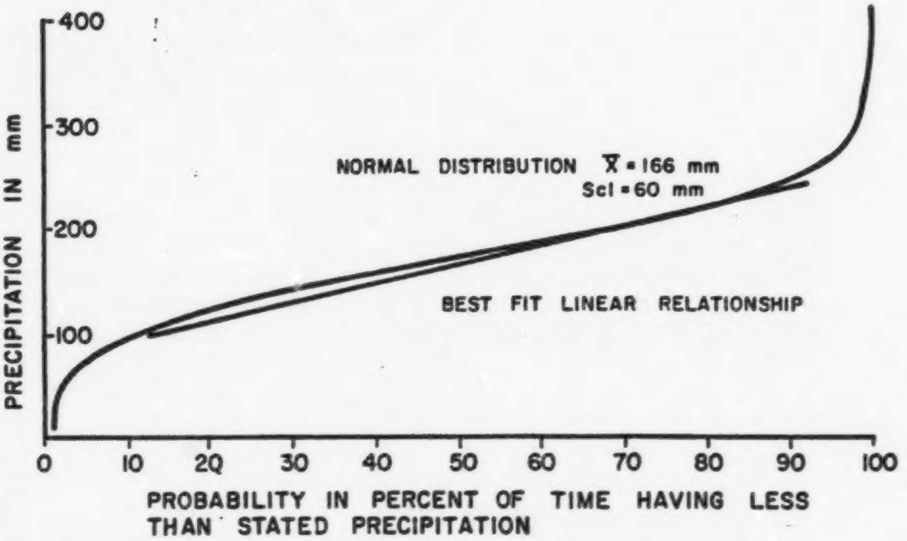


Table I. Comparison of Actual Precipitation to that Calculated from Linear Relationships.

PROBABILITY LEVEL	ACTUAL PRECIPITATION MM	RELATIONSHIPS FROM 10-90% PROBABILITY	RELATIONSHIPS FROM 16-84% PROBABILITY	RELATIONSHIPS FROM 2 - 98% PROBABILITY
10	89	93	98	83
20	116	111	115	103
30	134	129	132	114
40	151	147	148	144
50	166	166	163	166
60	181	184	182	186
70	198	202	199	207
80	216	220	216	228
90	242	238	232	249

This illustrates that reasonably accurate estimates of precipitation can be made using linear relationships in place of other distributions with the type of rainfall variability as found in Alberta.

The range of prediction was set at 10% to 90% probability for the following reasons:
(1) inspection suggested that linearity of the data decreased beyond this range.
(2) the analysis of the normal distribution based on the mean and standard deviation of Lethbridge data, and
(3) farm decisions are for the most part not based on the frequency of rare events.

In most cases the maximum risk many farmers will accept will be a serious loss in 1 out of 4 years which will restrict planning to a probability range of 25 to 75% rather than the 10 to 90% range used in this analysis.

As stated earlier the linear relationships will explain 95% or more of the variability at each station between probability and precipitation. When the data from all the selected stations in a soil zone is combined and the best fit relationship determined, the percentage of the variation of the dependent variable explained by the independent variable decreases.

Table II shows the percentage of variation explained for the several time periods.

Table II. Percent of Variability of Precipitation Explained by Linear Relationship

SOIL ZONE	MAY 1 JULY 31	MAY 1 AUG. 31	SEPT. 1 APR. 30
Brown	88	89	72
Dark Brown(S of Bow Riv)	88	89	86
Thin Black(N of Bow Riv)	81	81	85
Thin Black(S of Bow Riv)	87	81	41
Thin Black(N of Bow Riv)	92	90	78
Black	92	93	88
Dark Grey(N & E of Ed)	89	79	68
Dark Grey (W & N of Ed)	86	84	82
Peace River	84	82	53

It would appear that a single relationship can be used to describe the expected level of precipitation within each soil zone during the growing season. More care will be required in using this type of relationship during the remainder of the year. The greatest problems appear in the zones where both the data base is least sufficient and the soil zones poorly defined. The precipitation variability is also more marked in these zones particularly during the winter months.

Two comparisons of the real data to that projected by linear relationships for the station and soil zone are provided (Table III). The stations used in the comparison are Coronation and Medicine Hat. The data are for the May 1 - July 31 period.

TABLE III. Comparison of Probability of getting a Minimum Level of Precipitation.

CORONATION	75mm	100mm	125mm	150mm	175mm	200mm	225mm	250mm	275mm
Actual	97	87	67	52	34	24	16	8	2
Linear Relationship Station	-	87	70	54	48	22	5	-	-
Linear Relationship Soil Zone	-	90	74	59	43	27	11	-	-
MEDICINE HAT									
Actual	90	76	58	41	23	12			
Linear Relationship Station	94	76	58	41	23	6			
Linear Relationship Zone	92	74	56	37	19	-			

Note that linear relationships do not predict accurately beyond the 90% and 10% limits imposed during calculation.

The potential user of this information must decide if the use of a single relationship, a station relationship or the actual data will provide them with sufficient accuracy for their intended uses.

The information available from Alberta Agriculture on request include
a) copies of this paper
b) the probability tables developed for the stations
c) the linear equations describing the probabilities

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USE OF RADAR TO OBTAIN INTENSITY-DURATION ESTIMATES FOR RAINSTORMS

by L. Wojtiw
Alberta Research Council

1. Introduction

Rainstorms which exceed the design capacity of conveyance systems and cause extensive damage to structures and property, occur frequently in Alberta. After such a severe storm, an early and quick assessment of the storm's location and magnitude and the corresponding frequency for various durations is often required to evaluate the damage.

The procedure for evaluating the frequency of the rainstorm occurrence is to determine the maximum precipitation depth for each of several durations ranging from 5 minutes to 24 hours. The resulting curve is called a "storm intensity-duration curve". This curve is then compared with the intensity-duration curve of a selected frequency to the nearest recording raingauge to determine if the frequency of the event has been exceeded for any of the assessed durations. The storm intensity-duration frequency curve is produced with information obtained from a sparse network of recording tipping-bucket raingauges, thus, creating a high degree of uncertainty in the result. Since, there are few recording raingauges in Alberta (about 54 in total - one gauge per 22,000 km^2) necessitating the use of less accurate data, daily readings from the non-recording standard raingauge network, for interpolation of rainfall measurements.

Short-duration precipitation is usually quite variable in Alberta; hence a very dense network of recording precipitation stations would be required to provide precise measurements of the storm intensity-duration curve at all locations. Such a dense network does not exist in Alberta; it would be very expensive to install, maintain and thus difficult to justify financially.

One solution for obtaining a large amount of closely spaced intensity-duration values is to use weather radar. Radar can be used to delineate the intensity of rainfall for various durations over large areas; thus becoming a very useful hydrometeorological instrument. A weather radar can complement or replace traditional rainfall sensors. With the greater sampling frequency (3 minutes or less) and greater sampling density (roughly one value per square kilometre) offered by radar, a more complete description of rainfall events can be produced.

The Atmospheric Sciences Department (ASD) of the Alberta Research Council (ARC) has a radar that routinely obtains the precipitation measurements described above, and has also collected vast amounts of recorded data from past rainstorms (over 4000 computer tapes have been collected since 1975). The rainfall measurements obtained throughout the summer months by the weather radars operated by the ARC are potentially capable of providing intensity-duration curves for any location within 150 km of the radar site, which is located 10 km southwest of Red Deer. This is equivalent to obtaining rainfall information in an area extending from Edmonton in the north to Calgary in the south, and Coronation in the east to Brazeau in the west.

As a pilot project to demonstrate the feasibility of the method and the potential of the radar data, computer software was developed to derive from archived radar data, intensity-duration values for up to a 2,500 km^2 area for a given storm. To demonstrate the computer software, maps of intensity-duration values for three storms occurring between 1982 and 1984 were produced (Wojtiw, 1984). Before the software package is presented, interpretation of rainfall measurements from raingauges and radar is discussed to provide the reader with background on these topics.

2. Precipitation data from rain raingauges

2.1 Intensity-duration curves

The intensity-duration graph (also known as the Yarnell (1935) frequency graph) can be constructed from frequency analysis of short-duration point rainfall values. On this graph, rainfall intensity is usually displayed for durations from 5 minutes to 24 hours with curves drawn for the various return priods from 2 to 100 years. The intensity-duration curves are produced from available data by the national weather service (AES in Canada). An example of an intensity-duration graph for the Edmonton Municipal Airport in Alberta is shown in figure 1. For a given duration the user can then determine the intensity or amount for a desired return period. For example, for a 30-minute duration the rainfall rate for a 25-year return period is 65 mm/hour, or a 30-minute accumulation of about 32.5 mm of rainfall for the Edmonton Municipal Airport. Hence, if a rainstorm produced more than 32.5 mm in any 30 consecutive minutes during its lifetime, this storm would be regarded as having exceeded the 1-in-25 year event. Two main criteria necessary for obtaining intensity-duration information are: (1) the rainfall data should be collected on a short-time scale (for example, a 1-minute time interval is commonly used); and (2) the data should be collected over many years. The first criterion eliminates a large number of the rainfall observations in this province from being used for this purpose, since these are recorded hourly (for example, 6, 12 or 24 hours) rather than in minutes.

The second criterion is also important, because the record period has been identified to affect the confidence that can be placed in the interpretation of the rainfall information. The longer the record period the lower the variance (lower also are the 50 percent confidence limits) hence the greater the reliability of the results. Based on studies by Hershfield (1961) about 50 years of data can be regarded as the standard and this number is needed to provide a stable data set. Stations with period of records below this standard have an "error" (or a large variance) associated in the statistics of the annual series. Hershfield's work suggests that about a 30 percent error exists in the standard deviation, and a 5 percent error in the mean, if the station has only 10 years of available data. In Alberta, the rainfall intensity data from the AES stations have lengths of record ranging from 10 to 50 years. Most of these stations are far below the standard of 50 years advocated by Hershfield. When using this data, it needs to be remembered that the return period values may have an "error" associated with them; the values, because of the short record lengths, should not be regarded as precise.

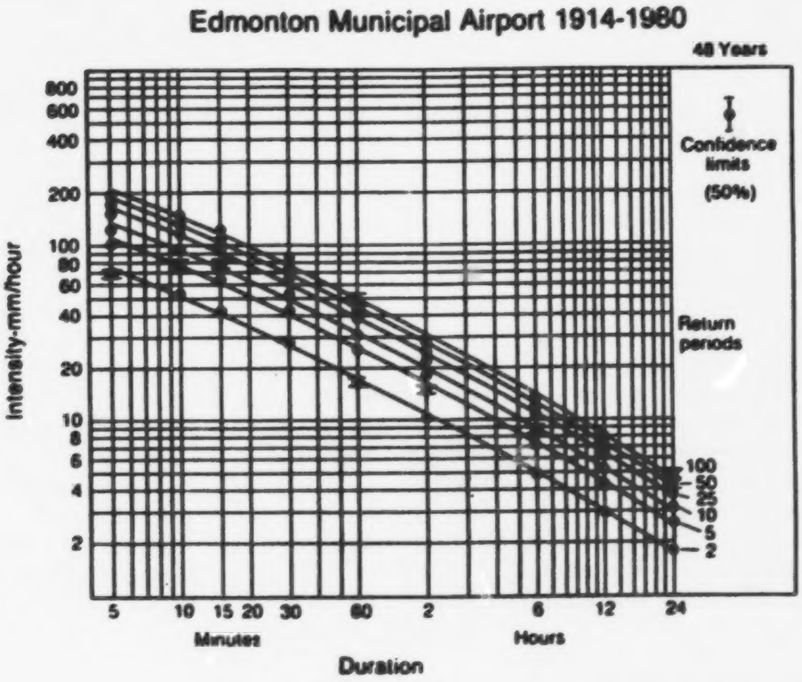

Figure 1. Intensity-duration graph for the Edmonton Municipal Airport. Note that the quantities are plotted on logarithmic scales (unreferenced AES publication).

2.2 Representation of point rainfall observations

The data used in the intensity-duration analysis are collected by a tipping-bucket raingauge which has about a 324 cm^2 catchment area. These point values are frequently assumed to be representative of a 65 km^2 (25 mi^2) area. Conversions of point values to areal measurements for rainfall has been examined by various authors (for example, Court, 1961; Hershfield, 1961; McKay, 1965). It is generally accepted that for steady rainfall over many hours, the point measurements can be extrapolated to a 65 km^2 area without error. In thunderstorms, where heavy short-duration rainfall can occur, assigning a 65 km^2 area to a point value is questionable. In fact, for such storms in some cases it is questionable whether the point observations can be considered to be representative of an area as several square kilometers. Hence an adequate representation requires many closely spaced observations.

2.3 Density of rainfall observations

Another concern that exists with intensity-duration rainfall measurements is the inadequate density of observations. Even assuming that a 65 km^2 area can be represented by a point measurement, to obtain sufficient information on rainstorms, hundreds of tipping-bucket raingauges would be needed to adequately cover a typical rainstorm in Alberta. Vershuren and Wojtiw (1980) showed that rainstorms in Alberta which produce a maximum depth of 50 mm or more cover areas of thousands of square kilometers. Since few tipping-bucket raingauges exist in Alberta, for much of the rural area very little or no information exists to determine if flooding may have occurred from severe rainstorms. Establishing large networks of tipping-bucket raingauges is very costly and time consuming. Yet, greater resolution of rainfall rates and amounts is desired by engineers, hydrologists, meteorologists and users of water resources. Hence it is not surprising that a greater emphasis has now been directed to apply remote sensing instrumentation to the collection of precipitation measurements. Radar is being more frequently used in hydrological applications to obtain many closely spaced short-duration rainfall amounts.

3. Radar measurements and interpretation

"Radar" is an acronym used since World War II to describe the technique and equipment employed for the "Radio Detection and Ranging" of objects in the atmosphere. Meteorologists use radar (known as weather radar) to detect, locate and measure the amount of precipitation in clouds.

The microwave beam transmitted by weather radar will pass through cloud and fog but when it strikes precipitation particles, such as raindrops, snowflakes or hail some of the energy is back-scattered as an "echo" to the radar antenna. The amount of energy scattered back to the radar is related to the precipitation intensity. Since both the speed at which the microwaves travel (at the speed of light) and the direction in which the antenna is pointing are known, the distance and direction of the precipitation from the radar transmitter can be determined from the radar echoes. This permits the mapping of precipitation over the area covered by the radar.

3.1 Relationship between radar reflectivity and precipitation rate

Empirical studies indicate that a relationship exists between the radar reflectivity factor, Z and precipitation intensity, R, hence radar can be employed for estimating rainfall rate or amount. Some scientists have visualized that radars, which can observe rainfall over a very large area, ultimately will replace raingauges. Others have taken the position that radar should complement raingauges and when used together, would provide significantly better information on the rainfall than can be obtained solely from a raingauge network. Various studies have been made to test the validity of the equation relating backscattered power to rainfall intensity. Direct observations of rainfall have been compared with calculations made from simultaneous radar observations. In general, the investigations have shown that properly calibrated radars can make reasonably accurate measurements of rainfall intensity and of accumulated rainfall over a small watershed. The Radar Equation (Probert-Jones, 1962) under certain assumptions (for example, use of 10 cm radar; radar is observing rain; rain consists of spherical water drops small enough to permit the Rayleigh approximation to apply) and knowing the radar characteristics can be expressed as a relationship between A and the precipitation rate, R.

In order to use radar for measuring rainfall intensity, most investigators have employed an empirical expression of the form

$$Z = A \quad R^{b} \tag{1}$$

where Z (mm^6/m^3), A is a coefficient to be determined, R (mm/hour), and b is an exponent to be determined. Battan (1973) provides a list of various relationships that have been reported in international literature. Although the equations listed in Battan differ markedly at small and large values of R, with the exception of curves for orographic rains, most of them do not differ greatly at rainfall intensities between about 20 and 200 mm/hour. The Marshall-Palmer (1948) relationship, $Z = 200\ R^{1.6}$, was developed in the early history of radar meteorology from Canadian data (in eastern Canada) collected in temperature zone rain usually stratiform in nature. In the past it has been common when other information has been lacking to use this relationship for all types of rainfall. Battan suggests that this procedure is no longer appropriate.

The lack of many tipping-bucket data within radar coverage has slowed progress in the development of a Z-R ralationship for rainfall in Alberta. Usually a single rainstorm covers very few raingauges thus making calibration difficult. Three Z-R relationships are investigated in this paper to determine which relationship is best suited for Alberta rainstorms. The relationships investigated are: (1) the Marshall-Palmer ($A=200$, $b=1.6$), because it is regarded as the classical relationship; (2) the Hood (1950) ($A=295$, $b=1.61$) because this was developed for Canadian rainstorms; and (3) the Wojtiw (1984) ($A=168$, $b=1.72$) developed for three Alberta rainstorms (including the July 5, 1984 storm).

The July 5, 1984 rainstorm passed through the city of Edmonton where 11 raingauges within ASD radar coverage area were operated by Edmonton Water and Sanitation Department. This is one of the few storms that have occurred in Alberta for which a number of raingauge measurements are available, to help calibrate a Z-R relationship. In figure 2 (Wojtiw, 1984) the rainfall rate (horizontal axis) was obtained from surface tipping-bucket data, while the reflectivity (horizontal axis) came from the S-band 10 cm radar near Red Deer.

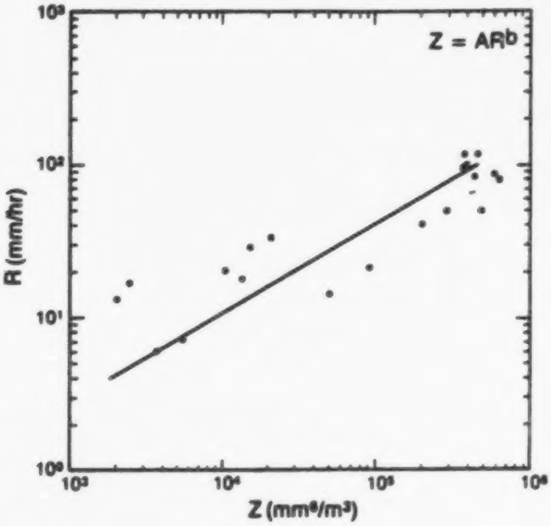

FIGURE 2. Z-R relationship developed for Alberta rainstorms

The rainfall rate was the rainfall rate occurring in the 5 and 10 minute intervals of the lifetime of the rainstorm, while the reflectivity was the time-integrated average over the corresponding durations. The 5 minute rainfall amount was the minimum duration readily available in the tipping-bucket data. The reflectivity value in the bin (areal coverage of one value of radar data representing approximately about 1 km^2 area) closest to the surface measurement was selected for the comparison. The straight line shown in figure 2 is the best-fit equation, with coefficient A=168 and b=1.72 (in equation 1), and with a correlation coefficient of 0.83.

From all indications this Z-R relationship gave results which were in good agreement with surface observations. The comparison between maximum rainfall amounts derived from radar data and recorded by surface raingauges for the three different Z-R relationships and the three cases is shown in figure 3. The solid line in figure 3 is the one-to-one line representing the exact correspondence of the two amounts. Deviation form this line either up or down indicates differences between the measurements. The results for the three relationships show that the Wojtiw Z-R relationship overall gives estimates of the maximum rainfall amounts closer to the ground measurements for Alberta rainstorms than either of the other two relationships (Marshall-Palmer or Hood). The results are particularly good for the higher rain amounts (greater than 5 mm).

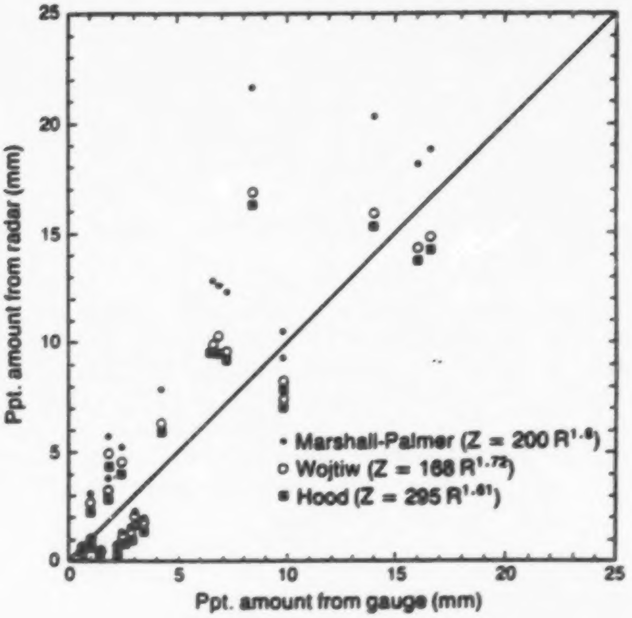

Figure 3. Comparison between radar and surface raingauge estimates of maximum rainfall for the three Z-R relationships.

4. Data management and computer software development

Weather radars and rainfall gauges can provide improved rainfall measurments, but in order to take full advantage of this technology, the data must be readily accessible and in a form easy to comprehend. Unfortunately, this is not the case for most weather radar facilities. Typically, raw radar data are recorded on computer-compatible magnetic tapes as numbers (usually as binary numbers) which mean nothing to the user who is interested in rainfall rate or amount. The data must therefore be transformed into a usable format; this becomes a question of data management. The raw received digital data, using the electrical calibrations and the radar equation are automatically converted into received powers or equivalent radar reflectivity factors or both (Barge et al., 1976, describe how this is accomplished for the ARC radars). The data are now in units ready for use by radar meteorologists.

The amount of data stored on a computer tape is a function of the storm size and duration. For example, a single scan at approximately the same elevation for the full coverage of the radar results in over 50,000 values being collected every 1.5 minutes (or over 2 million values in an hour). In practice, the number of values recorded is much less, since the storm usually covers a small portion of the total area covered by the radar. At this stage the application of the radar data determines the direction of computer software development. In the present study, maximum accumulated rainfall amounts in a given area are needed for various time durations. Because heavy rainstorms in Alberta may last many hours or even days and the radar collects information continuously for 150 km in range (one value for approximately each kilometer) every degree up to 360 degrees in azimuth and up to 20 degrees in elevation, storage considerations become critical; thus the data needs to be compacted for easier data management and manipulation.

Two computer software packages were developed to facilitate storage compaction in obtaining maximum rainfall amounts for specific durations in a selected area. The first package uses the ASD-VAX system while the second package uses the ARC-VAX system. Both systems are interconnected allowing transfer of data and computer software to either system. The advantage of having the different packages available on the systems is that the user can still obtain a product even through one of the systems may be inoperative.

4.1 ARC-VAX computer software package

The first component of software development is to obtain radar information for a specific location and elevation (instead of the various elevations up to 8 or 20 degrees for the S-band, and up to 6 degrees for the C-band) that are stored on the magnetic tape. This can be accomplished through a modified version of a software routine called FOUR (modifying the resulting format) by specifying the area desired. The FOUR program produces a sequential file of unknown size depending on available data for the time required and contains: (1) the azimuth angle; (2) the bin number (equivalent to the range from the center of the radar); (3) the time to the nearest second and (4) reflectivity. Concatenation of radar data from several tapes can be easily carried out by re-running the FOUR program. The resulting computer file from FOUR is next transferred to the ARC-VAX computer where a software package with comand files has been developed to perform the necessary computations and plots to produce a final product.

In estimating the maximum rainfall amount for a given duration, it is first desirable to obtain the time-distribution of the dBZ reflectivities for each bin. The output resulting from the FOUR program does not readily give this distribution. The time-distribution is obtained in the software package by restructuring the data file so that for each bin the values of the reflectivities are sequentially ordered by time (this is accomplished by sorting the data file for bin number and time). Next, the computer package creates a sequence of reflectivities for each time of the duration of the storm, resulting in a time-distribution of reflectivities for each bin. These are next converted to rainfall rate by the Z-R relationship with the user having the option of providing the A and b constants or using the default values (for example, A=168 and b=1.72). This results in a time-distribution of rainfall amounts for each bin. Next, each time-distribution of rainfall amount is computer-searched to obtain the maximum amount for the specified duration. Nine different durations (5, 10, 15 30 minutes, 1, 2, 6, 12, and 24 hour durations) are programmed. The results contain for each specified bin (range and azimuth) the maximum rainfall amount which occurred in any 5 minute duration during the storm, any 10 minute duration, and so on. The results now contain the desired numerical values of rainfall amounts.

The user may want to examine a large area and it is not efficient to hand-plot hundreds or thousands of numerical values. Thus contouring and plotting routines are utilized for more rapid computer production. Two computer programs are used: (1) GEOPLTR and (2) SURFACE II. The GEOPLTR is an interactive computer package for the production of plotted maps on various map scales (user selected) of areally distributed data within Alberta. The second package (also interactive) invoked is the SURFACE II package which provides contoured observations. An example of the product available is shown in figure 4, where the maximum 5 minute intensity-duration values for the July 5, 1984 storm are shown.

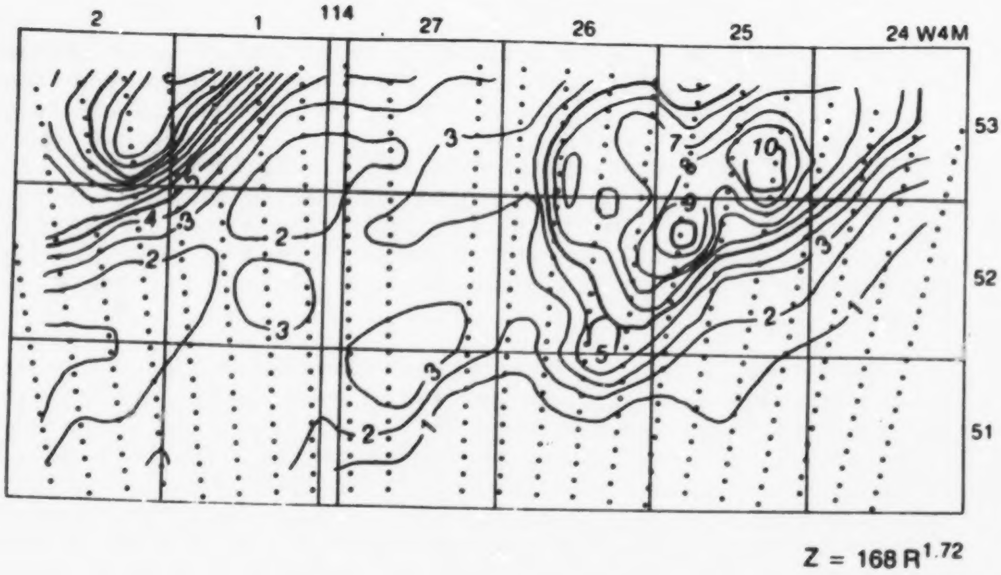

Figure 4. An example of the maximum 5 minute intensity-duration values for the July 5, 1984 storm.

4.2 ASD-VAX computer software package

The ASD-VAX package requires similar decisions by the user (for example, area, time) to the previous package. It does differ in two respects. First, a maximum area of about 625 km can be selected at any one pass, in fixed 25 degree azimuth intervals starting with 0 degrees and fixed 25 bin range intervals. Second, the final map is produced on a fixed scale of 1:500,000 (a scale used most frequently in ASD).

5. Summary and conclusions

Two computer software packages were developed in this study to produce maps of radar-derived maximum rainfall amounts for nine different durations ranging from 5 minutes to 24 hours. Although the computer packages require minimum user interaction, they offer a variety of possible selections; including the choice of selecting the Z-R relationship, the map scale and/or the contour interval.

Several conclusions were reached in the course of this study:

(1) Weather radar data can be made readily available to hydrologists to provide more objective assessments of rainfall from severe rainstorms and where the water exceeded conveyance criteria.

(2) Weather radar data can provide a much larger number of estimates of rainfall amounts than is presently produced by conventional networks in Alberta.

(3) The empirical Z-R relationship developed in Wojtiw (1984) shows a better correspondence between radar and ground observations for Alberta rainstorms (in the limited number of cases tested) than either the *Marshall-Palmer or Hood relationships*. It is recommended that work on the Z-R relationship continue in Alberta.

(4) Maps of maximum rainfall amounts for nine different durations can be produced in a relatively short time period (within a few days); and

(5) The computer software can easily handle analysis of areas of about 500 km^2 without exceeding storage capabilities or requiring extensive computer time. (Originally, it was believed that such large areas could not be handled.)

6. Acknowledgments

The author would like to thank C. Ewing and A. Krol of the Alberta Research Council, for some of the computer software development and application; to the Hydrology Division of Alberta Environment for funding this study; to Alberta Agriculture for providing funds to collect the radar data; and the City of Edmonton (Water and Sanitation Department) and Atmospheric Environment Service for raingauge rainfall data.

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THE MT. ALLAN - CANMORE WEATHER MONITORING NETWORKS

Patricia J. Gourlay-Papirnik

In February 1988, Calgary, Alberta will play host to the XV Winter Olympic Games. A commitment was made by the Government of Alberta to develop cross-country, biathlon and alpine facilities as well as provide financial support to other development programs. As part of this commitment, the decision was made to undertake comprehensive weather investigations, and an ongoing monitoring program was initiated.

In 1983 Alberta Environment was asked to co-ordinate this program with the Olympic Secretariat. Alberta Environment is responsible for identifying technical requirements and defining, implementing and monitoring the work program. It is funded by the Alberta Olympic Secretariat.

In the very early stages of planning for the Olympics it was recognized that climate is an important consideration in ski resort development and operations. Climate was one aspect considered in the Master Plan prepared for the Mt. Allan site. Variables such as solar radiation, microclimate influences, avalanche hazards, temperature, precipitation and wind were considered. In late 1983 it was decided to implement a short term monitoring project and to begin planning a semi-permanent long term weather monitoring project. The project was designed to address a number of concerns including assessing the impact of local climate on the optimum operation and utilization of the proposed ski facilities, and fulfilling the requirements of the XV Olympic Winter Games Organizing Committee (OCO '88). Both competitive and long term recreational needs were to be considered.

This presentation will provide an overview of the weather monitoring networks installed at Mt. Allan and Canmore for the alpine and nordic activities. Both sites are situated in the eastern slopes of the Rocky Mountains. Mt. Allan is located 90 kilometres west of Calgary. The Canmore Nordic Centre will be located northwest of the town of Canmore.

The Monitoring Networks

The process of selecting a contractor and installing the weather stations is lengthy and involved. The process begins with the writing of detailed terms of reference which outline the work and provide guidelines to ensure the desired end-product. The terms of reference for this project were drafted by the project manager in the Research Management Division in consultation with the data users and the Olympic Secretariat. Five consulting groups responded to the request for proposal to design and maintain the networks. After a detailed review process the consultant was selected in the summer of 1984.

The consultant proposed to design a network and gather weather data which may influence the operation and final design of Mt. Allan and Canmore sites for alpine and nordic skiing events, respectively. This involved the skills of a consultant in ski safety and one cognizant of the interaction between weather and skiing. The proposal outlined several climatological elements which had to be considered. These included

- snow cover distribution
- chinook effects
- skier comfort and safety - wind temperature extremes
- racing needs - temperature, snow quality
- snow making potential - humidity, temperature
- lift operations - wind speed, direction, gusts
- operation safety - avalanche hazards
- snow pack maintenance.

These data were used not only for skiing activities but also for consideration in the base area infrastructure design. For example, buildings were to be designed to maximize the beneficial aspects of insolation and to provide the greatest user comfort.

3

Mt. Allan

The plan for Mt. Allan has been developed, and the ski trails cut. Preliminary construction of lifts and buildings has also started. Establishing a weather monitoring network in this mountain environment is difficult. Equipment must be designed to operate with low power requirements. In this case, solar power was used. It must operate in very cold temperatures, high winds and an icing environment. The instruments must be able to be unattended for long periods. It must be designed with data storage capabilities. The Mt. Allan network is designed to record data for 1 week. In the event of inaccessibility due to snow storms or high winds, 3 weeks of data have been successfully recorded with no loss of data.

The system chosen for Mt. Allan was Campbell Scientific CR21 data loggers and the associated wind and temperature sensors. The CR21 is designed to operate in harsh environments. It can record up to 9 channels of meteorological data. Basic statistical quantities can be computed, and data is automatically converted to engineering units. For the Mt. Allan network, solid state memory modules were used. These replaced the more temperature sensitive taperecorders used elsewhere.

The Mt. Allan network consists of 6 sites. These are positioned at ascending elevations up the mountain, at locations such as the top of the Olympic Ladies' Downhill where specific information is needed. Two sites, MA1 (1521 m) and MA3 (2255 m) are fully instrumented. In addition to the data processor, this includes a solar panel, a CS201 relative humidity/temperature probe and a MET ONE anemometer and wind direction sensor and a LICOR pyranometer. The height of the towers vary, depending on the height of the surrounding tree canopy. At the three other sites, wind data alone are collected. At MA2, there is a hygrothermograph only. An enormous amount of data are collected. Output is generated for hourly values and daily summaries produced. Those parameters which are summarized hourly consist of:

- mean wind speed
- mean wind vector magnitude
- standard deviation of the direction
- maximum wind gust, and time it occurred
- average temperature
- average relative humidity
- vapour pressure
- totalized solar radiation.

Canmore

The Canmore site, which will be used for the nordic events - crosscountry skiing and the biathlon - has a separate network. Because of budget limitations CR21 were not used for the whole network. The network consists of 8 sites aligned in a W-E transect. Two of the eight sites are equipped with CR21 and the same data as Mt. Allan are generated.

At the remaining sites only temperature and humidity data are measured and recorded by a hygrothermograph enclosed in a Stevenson screen. At one location, C6, the CR21 and hygrothermograph were colocated to allow for the comparison of data.

Before I go on to the data summaries, I would like to mention a few problems which have been faced. With the Mt. Allan network the data recovery rate has been very high, with a recovery rate of 98%. Some data have been lost because of a suspected bad memory location, a programming error, disruption of data because of construction. Finally, at the top of the "B" (Gold) Chair, the tower is leaning because of the weight of the uphill snow. Condensation in the storage module is suspected of causing a brief data loss at the base station location.

Data recovery is approximately 70% for the Canmore network. Problems with strip chart paper, ink and lost charts reduced this statistic.

Snow Survey

In addition to the temperature and wind data collected snow surveys were conducted at Mt. Allan and Canmore. The purpose of the snow surveys was to describe snow cover distribution in relation to changes in elevation, and aspect, forest canopy openings snow transport by wind and chinook events. The snow survey locations were visited once a week from October to May on Mt. Allan and from October to March at Canmore.

Snow depth measurements are taken from 3 snow courses on Mt. Allan. Each snow course consisted of 8 measurement points. The courses range in elevation, from 1515 m to 2255 m. By the end of March approximately 40 cm of snow remained on the lower slopes. An eight point course located at the "A" (Silver) Chair, approximately midmountain, has snow at the end of March ranging from 17 to 72 cm, averaging 40 cm. High on the mountain there was a great variation in snow depth. By the end of March, snow depth averaged 78 cm with a range from 21 to 250 cm.

Additional snow measurements are made on Mt. Allan. There are two snow study plots where the amount of snow fallen since the last measurement period is recorded. These sites are located at the 1515 m and 1915 m elevation. There are also 11 visual survey locations.

There are four snow courses at the Canmore site. By the end of March, the lower sites were losing snow and averaged 23.5 cm, while the upper sites had an average of 45 cm of snow.

Data Summary

The data for this first year of the network have been briefly summarized.

In the temperature and humidity data for Mt. Allan we have measurements of minimum, maximum and daily mean temperatures. Daily minimum temperatures at the Base Station were -13.0 °C. During January and February, the coldest months, daily mean temperatures were -8.3 °C and -8.0 °C. Daily humidity values vary, with mean values approximately 53% to 70% daily.

Temperatures at MA3 are slightly colder and more humid. The coldest months were December and February.

The wind data for Mt. Allan are more extensive (Figures 1 and 2). Each graph shows mean wind speed, maximum wind speed, wind variability, and on the right axis, the prevailing direction. The maximum wind speed is the maximum speed, in kilometers per hour, sustained for one hour. The wind variability parameter is a measure of the variation in the mean wind speed. Seventy five percent of the winds were below the indicated speed. Wind direction is relatively constant at each location.

At MA1, winds are moderate, in most cases 75% of the winds are slower than 40 km/h. Winds are most prevalent fom the southwest. Mean wind speeds are often less than 10 km/h. At MA3, mean wind speeds still average 10 km/h. The wind direction has shifted to the west northwest. Maximum wind speed is approximately 20 km/h for October, March and April. Maximum wind speeds reached 50 km/h in December and January.

At the Canmore Stadium area mean windspeeds are low, averaging 8 km/h. Prevailing wind direction is consistently from the NW. Similar conditions show up at the Old Mine Site, C6, as shown in Figures 3 and 4.

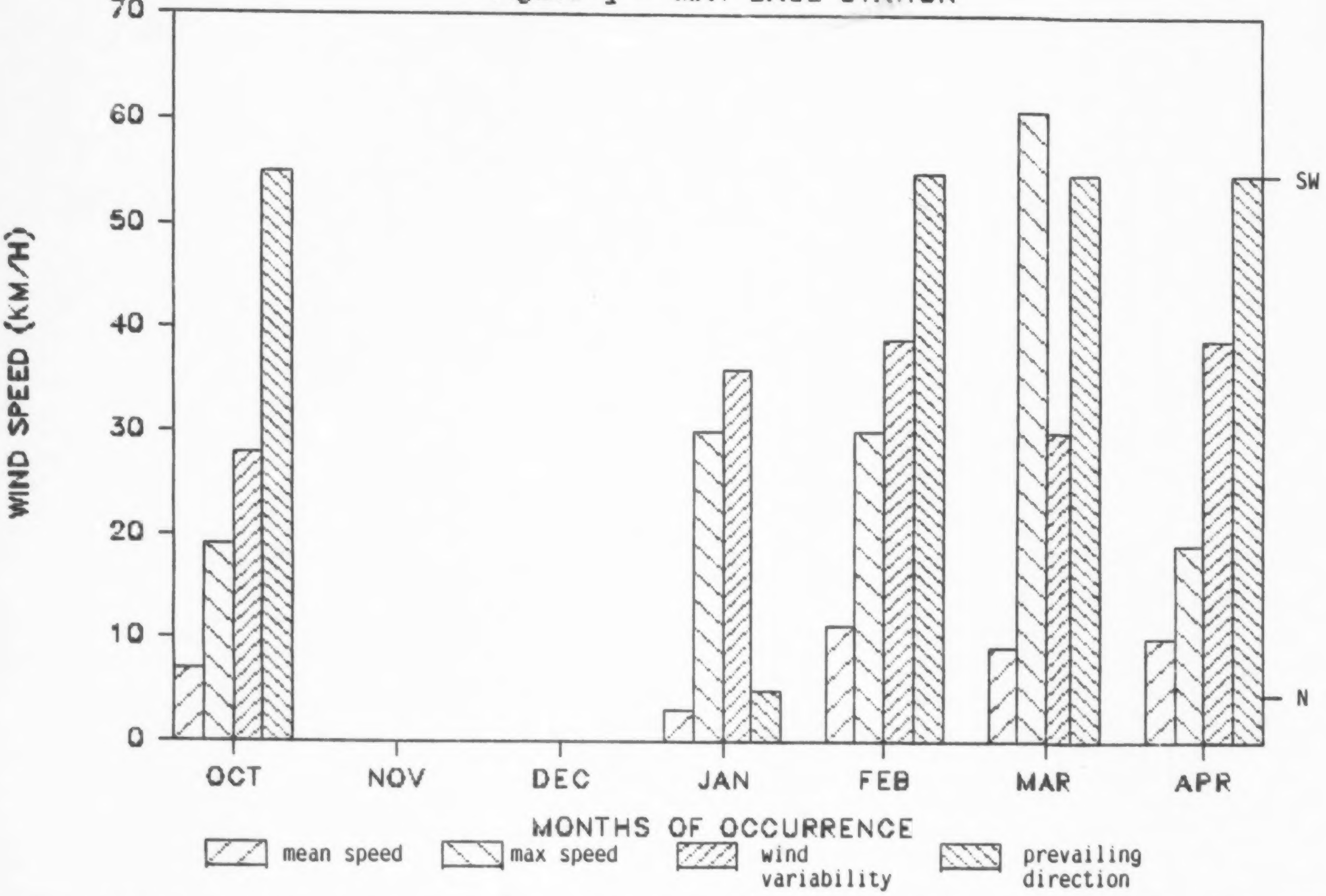
Summary

This has been a brief summary of the weather data from Mt. Allan and Canmore. This monitoring will continue during the 1985/86 and 1986/87 winter. Thus, competitors, coaches and planners will have a greater understanding of possible conditions to expect during the Olympics. These data will be analyzed fully to identify events such as chinooks. When sports commissioners were asked to rank meteorological parameters in order of importance to the sport, temperature, humidity and precipitation were ranked first by the nordic experts. Visibility, precipitation and wind statistics were desired by the alpine specialists. If during these preliminary seasons a specific problem is encountered such as wind scour or snow drifting mitigative procedures can be initiated to resolve them. These data have already been used in the design of the Olympic scoreboards.

The Mt. Allan and Canmore weather monitoring networks are examples of a unique application of meterological and climatological studies. Ideally, these centres will be used for both the competitive skier and the recreational participant long past the 1988 Olympics.

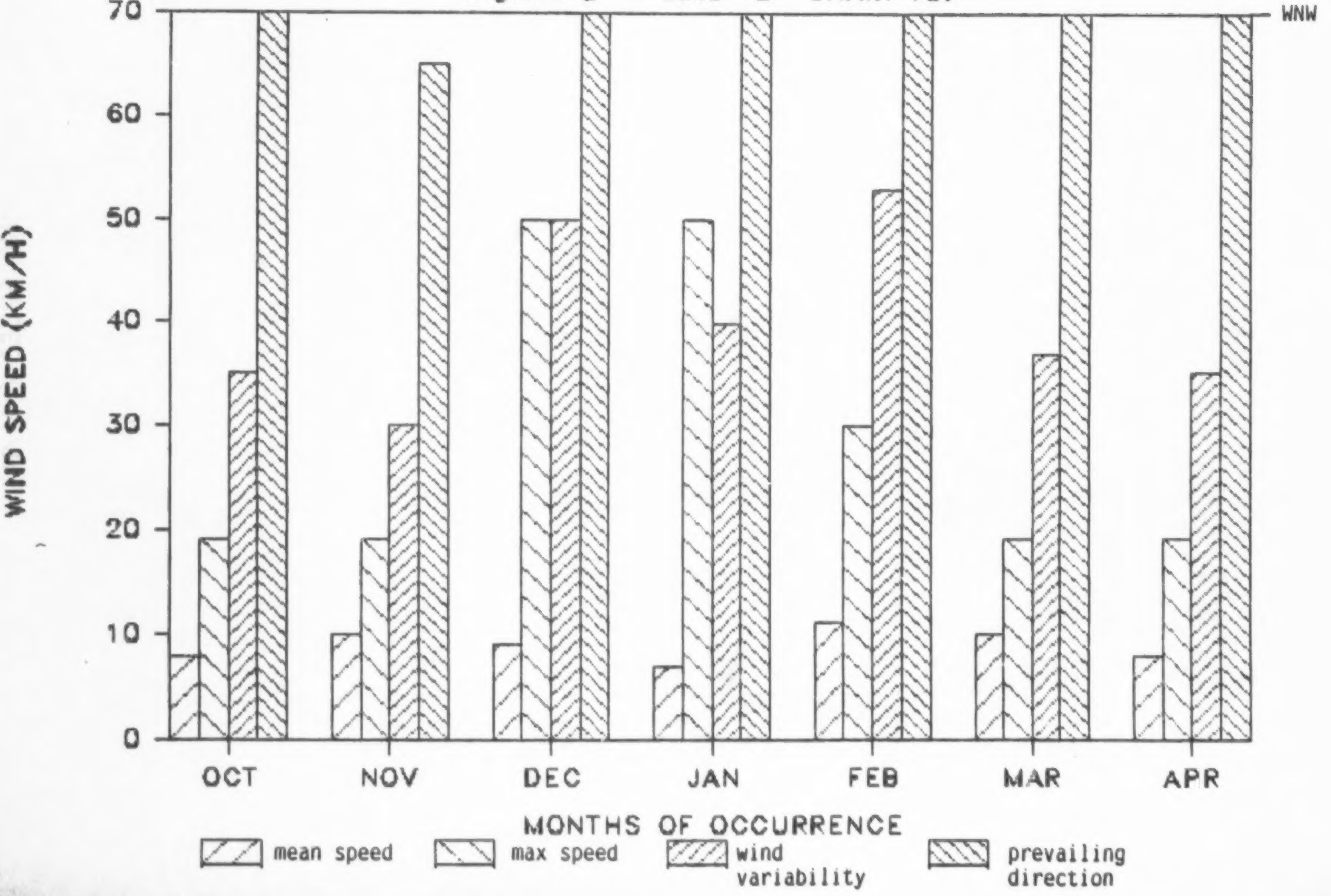
WIND DATA SUMMARY

Figure 1 - MA1 BASE STATION



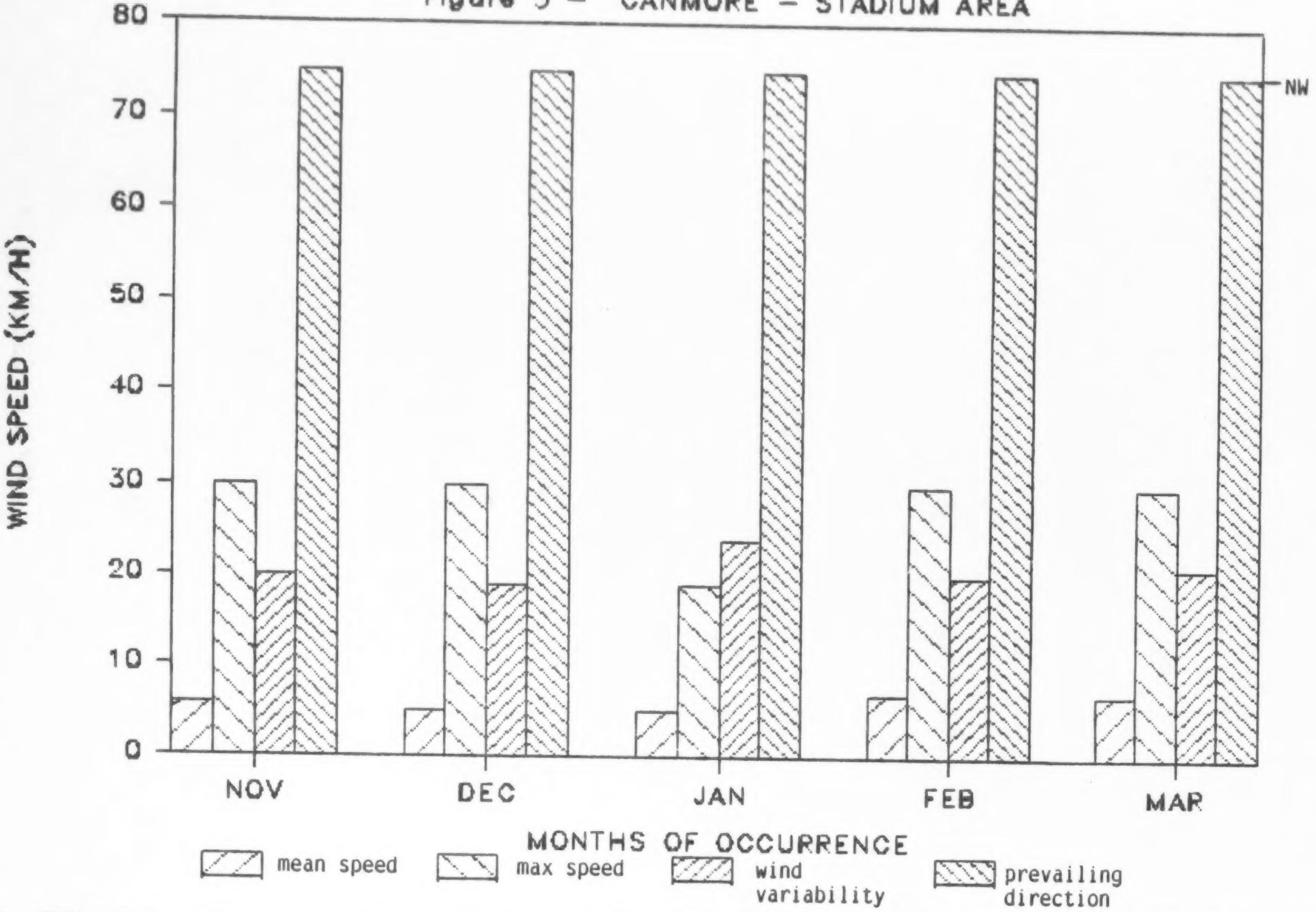
WIND DATA SUMMARY

Figure 2 – MA3 "B" CHAIR TOP



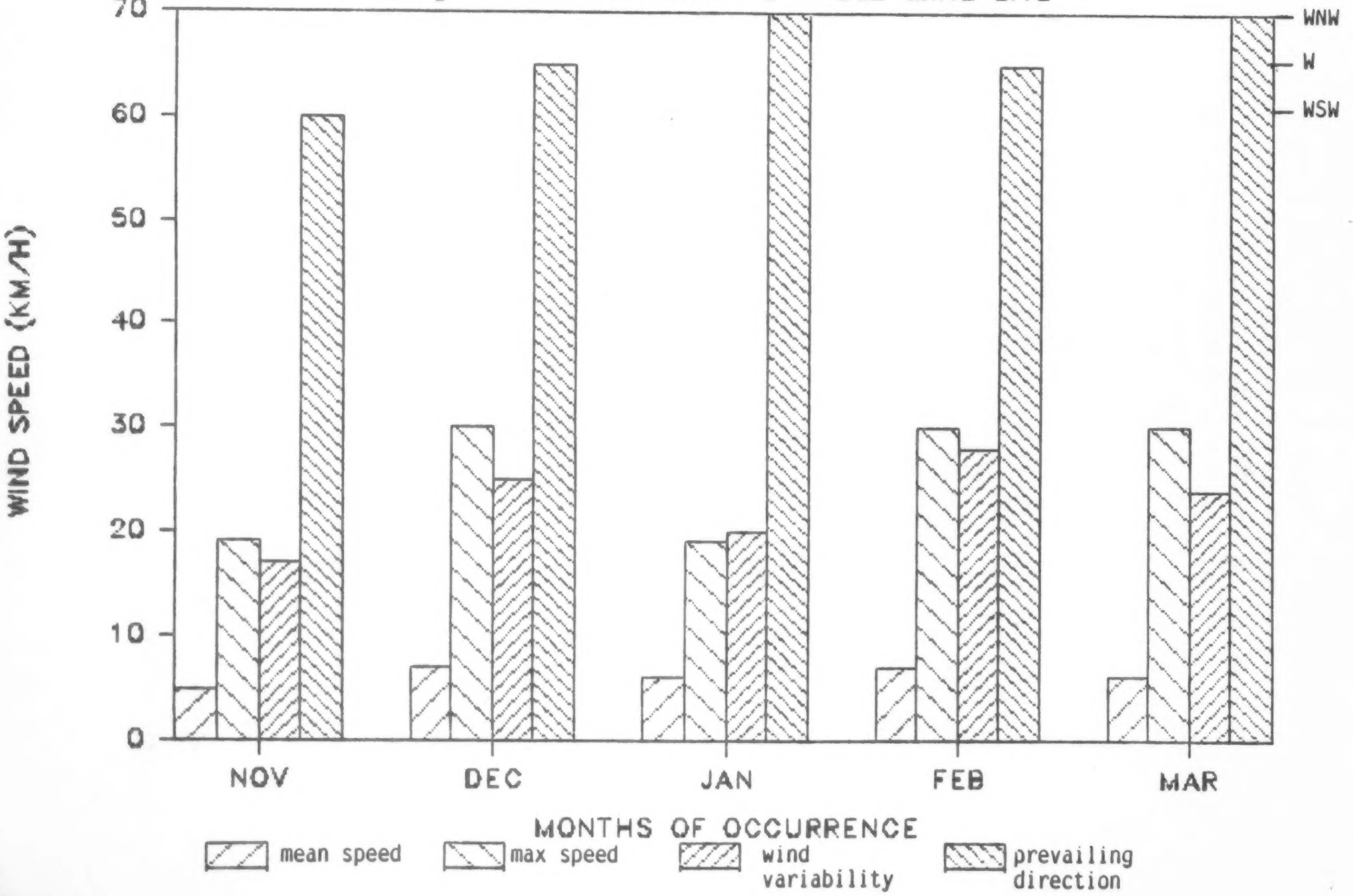
WIND DATA SUMMARY

Figure 3 - CANMORE - STADIUM AREA



WIND DATA SUMMARY

Figure 4 – CANMORE 6 – OLD MINE SITE



AGROCLIMATOLOGY OF THE LOWER PEACE RIVER REGION

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ABSTRACT

The climatology of the Lower Peace River Region is a key component in the assessment of potential agricultural lands. This paper describes some of the agroclimatic resources that allow crops to be grown at latitudes as high as 58°N.

INTRODUCTION

The rating of agricultural lands in Alberta is primarily based on detailed soil and landscape information. Climate is incorporated in one of two ways depending on the rating scheme used. In the "Storie Index" used by Energy and Natural Resources, the "frost-free period" is the only climatic variable used while in the Canada Land Inventory (CLI) a combination of frost-free period and annual rainfall have been used. In many cases the frost-free period, used in both systems, is interpolated from sparse station density such as the map reproduced in Figure 1A. Based on this small database, the Canada Land Inventory classed about 19% of the land base in Alberta or about 24 million acres as having climatic limitations (Figure 1B). Most of this land base is in the part of Alberta where the least amount of climate data existed.

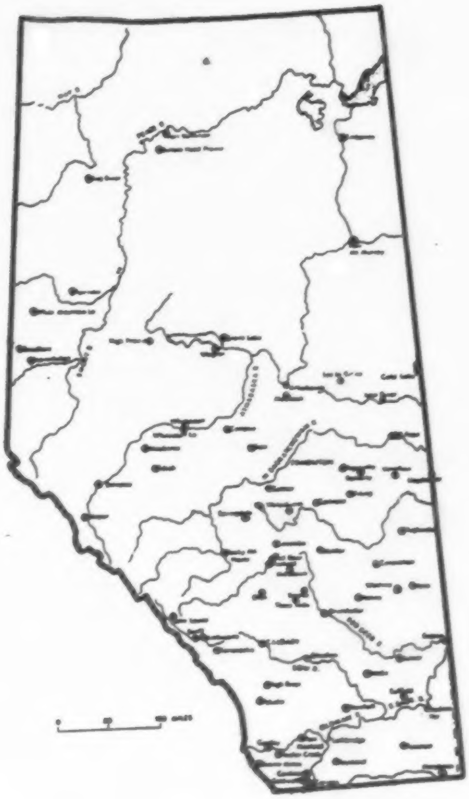


Figure 1A. Location of Stations with Frost-Free Period (1965)

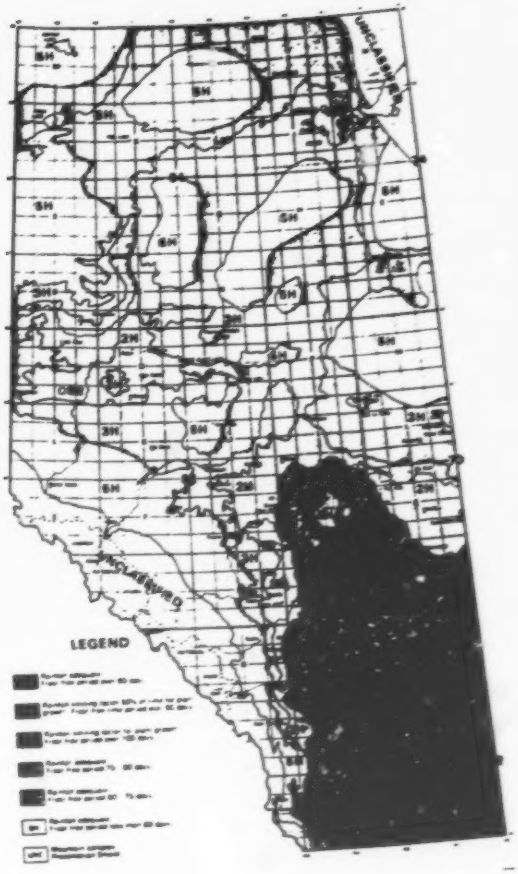


Figure 1B. Interpolated Information Using Frost-Free Period Data

Twenty years after these early maps, the number of long term climatic stations has improved (Figure 2). In addition to these, about 30 extra short term climatic stations have been operated by Energy and Natural Resources in a study area of the Lower Peace River Region. From this extensive dataset, a number of climatic maps have been derived including frost-free period, growing degree days, rainfall and seasonal moisture balance.

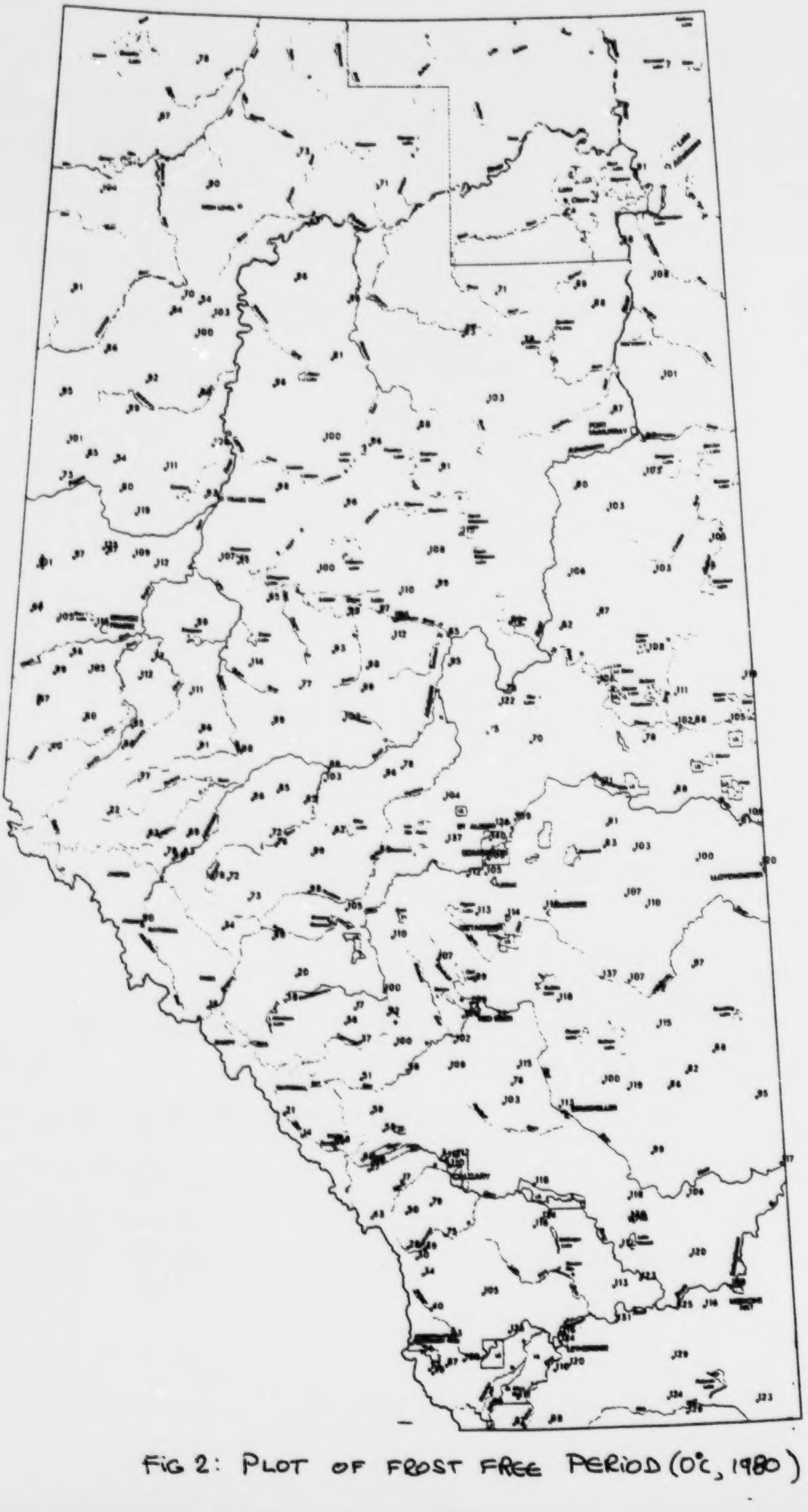


FIG 2: PLOT OF FROST FREE PERIOD (0°C, 1980)

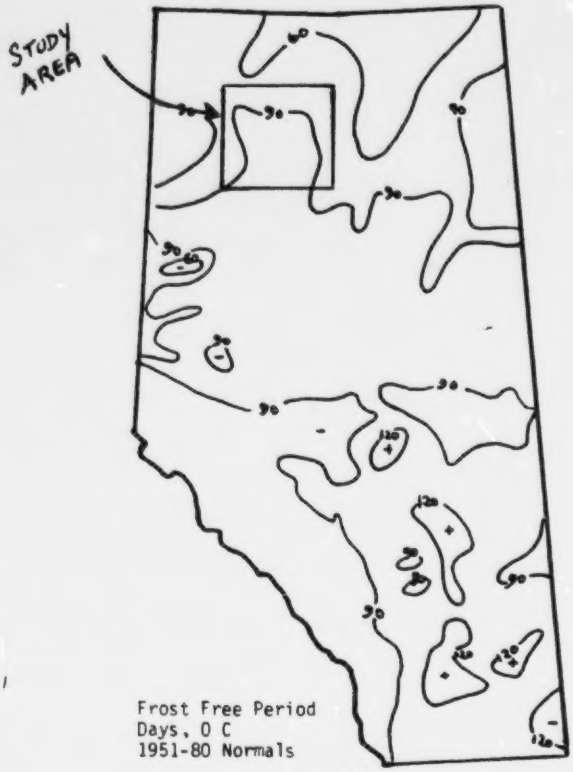
PROVINCIAL OVERVIEW

A number of low resolution provincial maps were drafted from updated 1951-80 data to provide a comparison of the study area to better known agricultural regions.

The average frost-free period at 0°C (Figure 3A) averages about 90 days in the study area which is about a month less than the southeastern part of the province. This 90 days, however, appears to be sufficient to grow crops in the region partly due to the effects of longer day length and partly due to faster maturing barley, wheat and canola varieties.

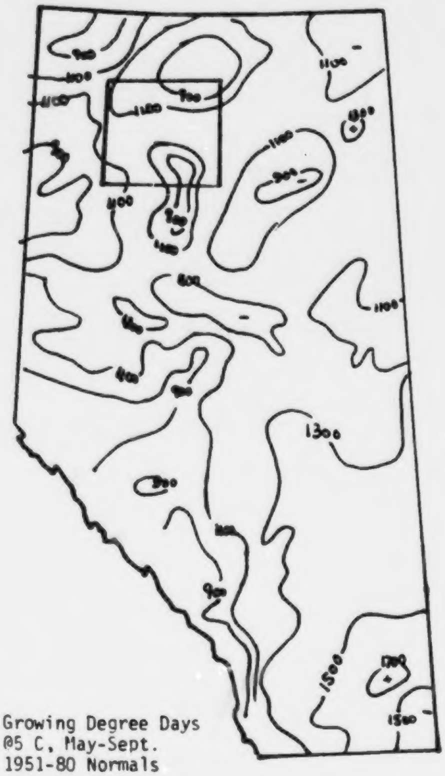
The seasonal accumulated growing degree days based on 5°C from May 1 to September 30 (Figure 3B) exceeds 1 100 dd over the Peace River lowlands and decreases to less than 90 dd over hills. The values are much less than southeastern Alberta where corn can be grown (if irrigated). It is interesting to note that Ft. Vermilion has similar degree day accumulation to Calgary which provides a good example of lower elevation effects despite higher latitudes.

Summer precipitation totals (Figure 3C) range from below 300 mm to over 400 mm from May 1 to September 30. These amounts are similar to that of south-central Alberta. The distribution of this total peaks in July in the Lower Peace River Region compared to June in southern Alberta.


STUDY AREA
60
90
120

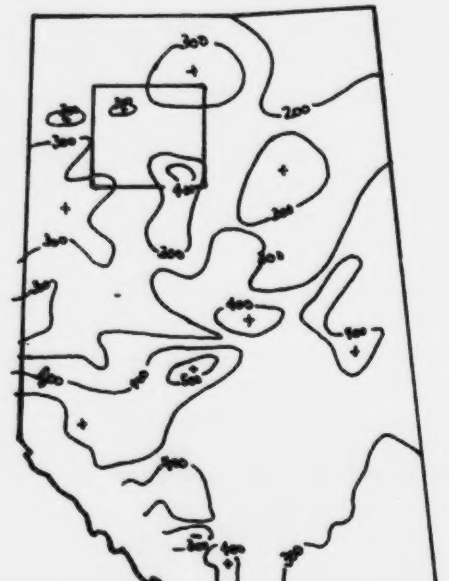
Frost Free Period
Days, 0 C
1951-80 Normals

Fig. 3A


900
1100
1300
1500

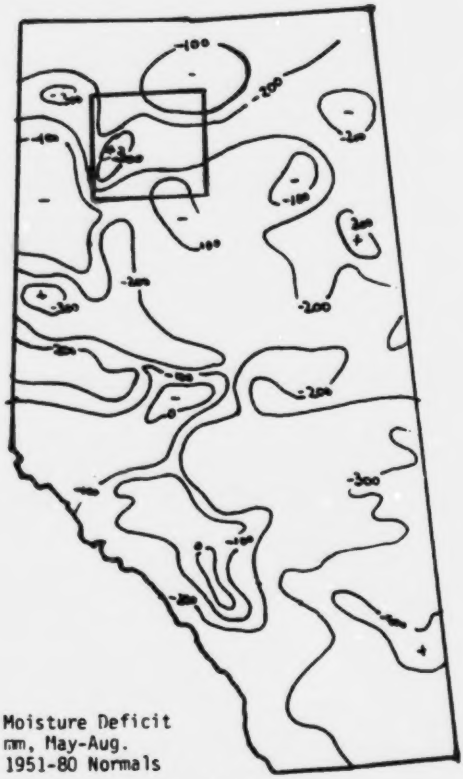
Growing Degree Days
@5 C, May-Sept.
1951-80 Normals

Fig. 3B



Summer Precipitation
mm, May-Sept.
1951-80 Normals

Fig. 3C



Moisture Deficit
mm, May-Aug.
1951-80 Normals

Fig. 3D

The moisture balance (Figure 4D) approximated by the rainfall minus potential evapotranspiration exceeds -300 mm over the lowlands to less than -100 mm over hills. The lowlands can be considered to be in a moisture deficient regime based on this simple approximation of moisture balance. Large variations in local moisture, however, occurs due to different soil textures, this tends to offset moisture stress over clay type soils while increasing it over sandy soils.

LOWER PEACE RIVER REGION DETAIL

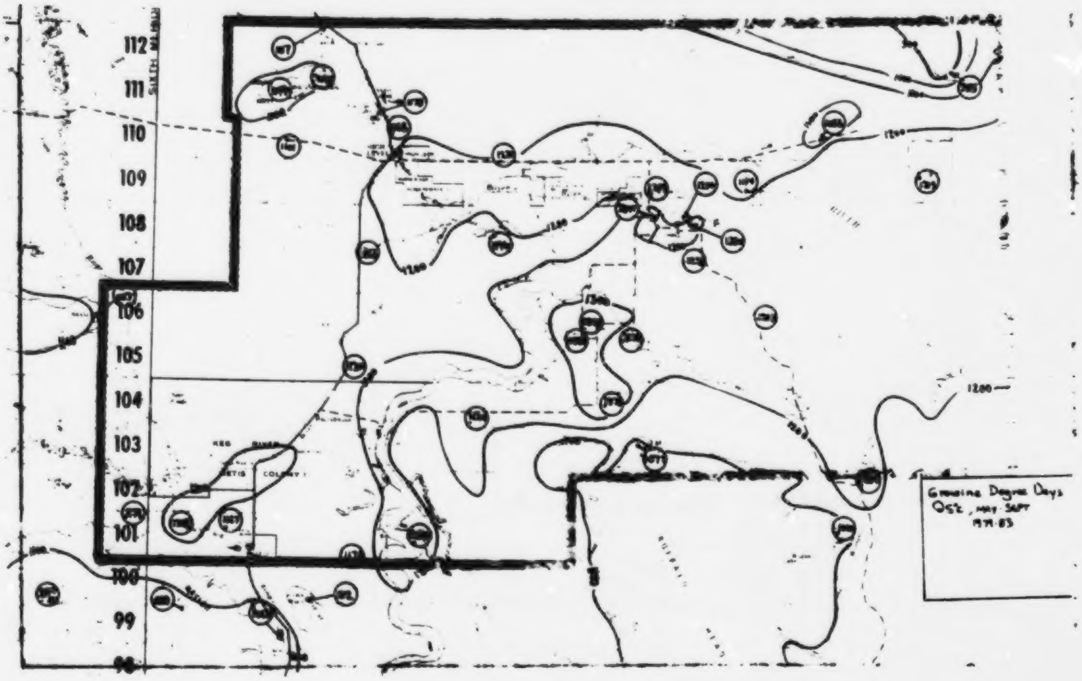
An extensive network of short and long term stations has been analyzed to map each climatic parameter in more detail for land use planning applications. In general the method consisted of statistical analysis and modelling to a digital terrain model which was then used to input to a 1 km grid for objective analysis. Elevations for each 1 km grid point were extracted from 1:50 000 topographic maps. Additionally, forest cover was taken from a LANDSAT mosaic and soil texture from an available soils survey database.

FROST FREE PERIOD (FFP)

Values ranged from a low of 47 days to a high of 105 days. There is some indications that longer frost free period occurred over well drained areas such as hill tops and are lower over poorly drained areas such as valleys and creeks. The forest cover also played a role in reducing FFP in that sites placed in clearings of less than about 200 x 200 m behaved as "hollows." This may be due to reduced effects of wind mixing or poor drainage. A statistical analysis based on terrain curvature, forest cover and elevation, however, revealed a poor regression coefficient (r^2) of .38. Based on this evidence it appears that frost-free period cannot be mapped to a land-base with any confidence. Each individual frost on clear nights may follow topography, but according to our findings, the frost free period is more of a function of timing dependent on random passages of cold fronts and clearing skies which are independent from local landforms.

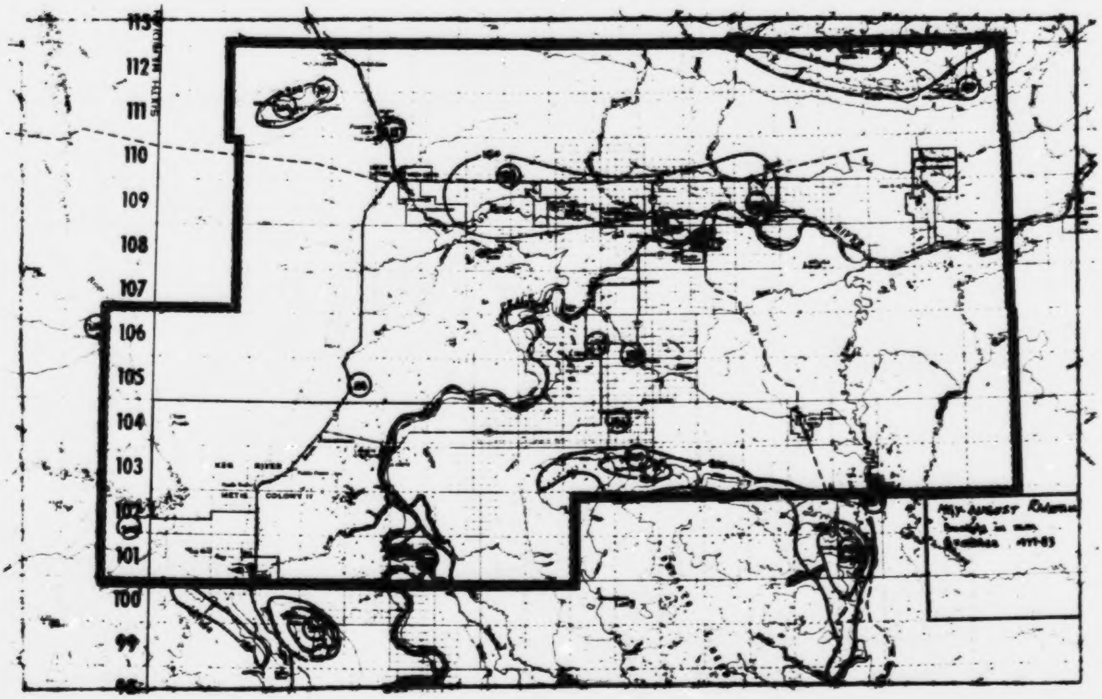
GROWING DEGREE DAYS (GDD)

Seasonal GDD above 5°C from May 1 to September 30 over the region ranged from a high of over 1 300 dd over the lowlands to less than 900 dd over hill tops. A statistical analysis showed a good (r^2 = .78) relationship between GDD and elevation, forest cover and slope. The dependence on forest cover suggested an increase of about 100 dd after clearing. Another interesting feature of GDD is its dependence on time. Significant increases over the long term were detected which tend to support climatic warming in the area.


112
111
110
109
108
107
106
105
104
103
102
101
100
99
1200
Growing Degree Days
O5°C, MAY-SEPT
1979-83

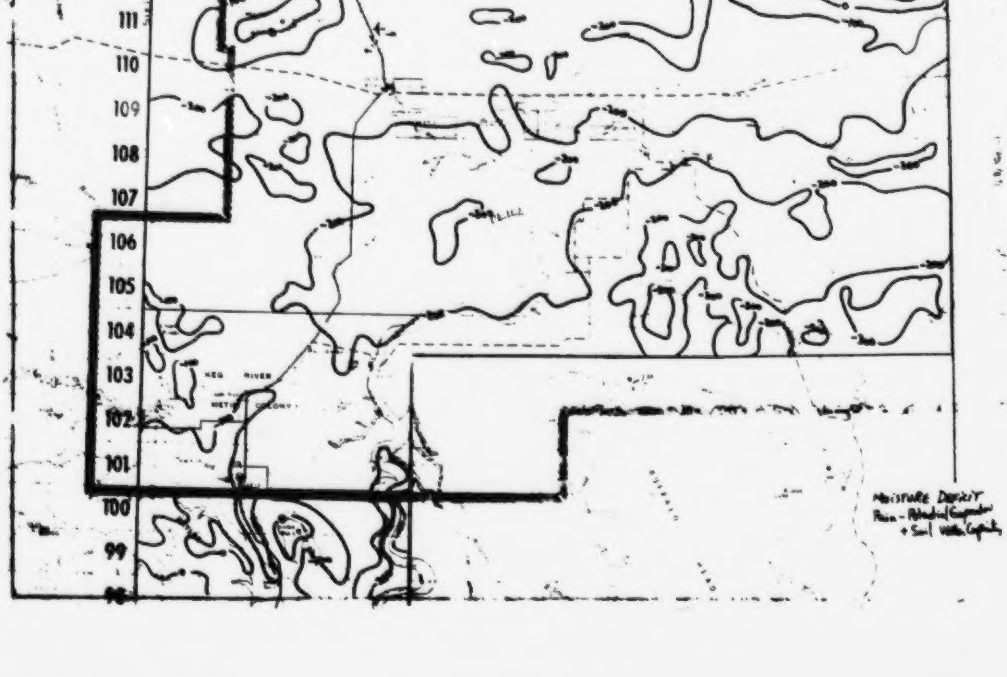
RAINFALL

Rainfall totals from May to August averaged between 150 mm over lowlands to over 300 mm over hills. Large inter-annual variation generally exceeded site to site variation. A statistical analysis revealed that a model based on terrain curvature and slope produced an r^2 of .71 and that elevation was not statistically relevant. The map produced reflected both the lack of variation along lowland terrain as well as higher rainfalls on steep slopes.


112
111
110
109
108
107
106
105
104
103
101
100
99
MAY-AUGUST
in mm

MOISTURE BALANCE

A simple model of rainfall - potential evaporation (PE) + soil holding capacity was attempted to describe overall seasonal moisture. In general, because of lack of variation of rainfall over most of the study area, moisture balance was generally a function of evaporation and water holding capacity. PE varied from 300 mm to 500 mm while soil holding capacity ranged from 40 mm for sandy soils to about 200 mm for clay soils. The map generated produced interesting results. In general, most of the area is in a moisture deficit regime while while hilltops have moisture excesses. Because groundwater seepage is not included in this model, the map also showed swamps as having moisture deficit!


113
112
111
110
109
108
107
106
105
104
103
102
101
100
99
98
KEG RIVER
METIS COLONY
MOISTURE DEFICIT
Rain - Potential Evaporation
+ Soil Water Capacity

CONCLUSIONS

The evaluation of agriculture potential in the Lower Peace River Valley is undergoing a rapid change both because of data availability and in assessment techniques. The strong emphasis on frost-free period of earlier systems have now been put into question when hilltops reflect higher values than surrounding farm land. An updated system is being developed jointly between Soil Survey, Alberta Agriculture and Public Lands of Alberta Energy and Natural Resources. As this system is finalized the climatic variables defined will be mapped in a process similar to the one presented in this paper and earlier papers (ACA Proceedings, 1984).

Experience Gained Operating Snow Pillows on a near Real-Time Basis in the Mountainous Areas of Alberta

by

G. A. Coles, P. Eng.[1], D. R. Graham, P. Eng.[2], R. D. Allison[3].

Introduction

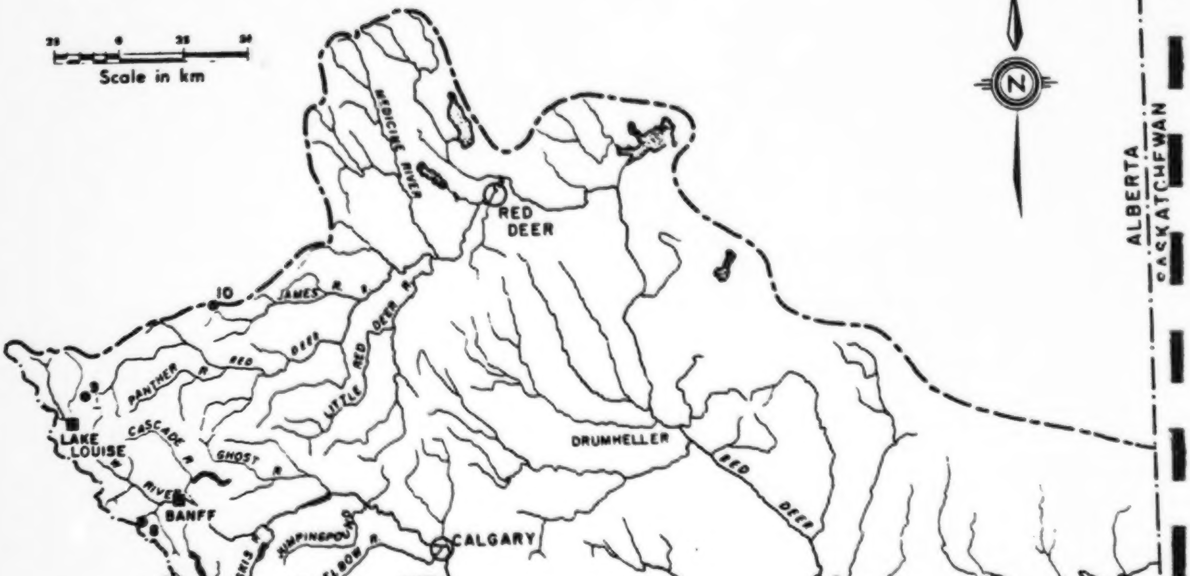
From a water management point of view, the South Saskatchewan River Basin (Figure 1) is probably the most important basin in Alberta. Limitations due to the availability of a reliable water supply are already placing constraints on the development of the industrial and agricultural potential of the basin which covers an area of approximately 111,000 sq. kilometres in Alberta. The water management problems have wider ramifications as an apportionment agreement exists between the Federal Government and the Prairie Provinces which requires Alberta to pass on to Saskatchewan fifty percent of the natural flow originating in the Province.

The South Saskatchewan River Basin is made up of three major sub-basins: the Red Deer, the Bow and the Oldman. All three of these rivers originate in the Eastern Slopes of the Rockies. These mountainous headwater areas have long been recognized as the key to the water supply and flood forecasting in Southern Alberta. However, until recent years, the collection of real-time water related data in the headwaters was extremely difficult due to the remoteness of the area, and the ruggedness of the terrain. For many years, most of the precipitation stations that existed in the area were storage gauges which were visited twice a year and only provided a winter and summer total accumulation of precipitation.

Presented at Workshop on Snow Property Measurement, Lake Louise, Alberta, 1985.

Mention of trade or company names in this paper is solely for the benefit of the reader.

1. Section Head, Water Survey Section, Alberta Environment, Edmonton.
2. Section Head, Procedures & Networks, River Forecast Centre, Alberta Environment, Edmonton.
3. Snow Surveyor, Water Survey Section, Alberta Environment, Lethbridge.


Scale in km
N
ALBERTA
SASKATCHEWAN
MEDICINE RIVER
RED DEER
10
JAMES R.
RED DEER R.
LITTLE RED DEER R.
PANTHER R.
RED DEER
LAKE LOUISE
CASCADE R.
GHOST R.
BOW RIVER
BANFF
DRUMHELLER
RED DEER R.
KANANASKIS R.
JUMPINGPOUND
ELBOW R.
CALGARY
BOW RIVER
BRITISH COLUMBIA
SHEEP R.
HIGHWOOD RIVER
SOUTH
OLDMAN R.
WILLOW CREEK
MEDICINE HAT
OLDMAN RIVER
LETHBRIDGE
CROWSNEST
CASTLE R.
PINCHER CR.
DRYWOOD
WATERTON R.
BELLY R.
LEE CR.
ST. MARY R.
CARDSTON
CANADA
U.S.A.
MONTANA
SNOW PILLOW SITES
1. AKAMINA CREEK
2. GARDINER CREEK
3. RACEHORSE CREEK
4. LOST CREEK
5. MOUNT ODLUM
6. THREE ISLE LAKE
7. LITTLE ELBOW SUMMIT
8. SUNSHINE VILLAGE
9. SKOKI MOUNTAIN
10. LIMESTONE RIDGE

ALBERTA ENVIRONMENT
MOUNTAIN SNOW PILLOW SITES
SOUTH SASKATCHEWAN RIVER BASIN
(ALBERTA)

MARCH, 1985

FIGURE 1

In addition to the precipitation network there were a number of snow survey sites in the mountain parks which were established and run by the water agencies of the Federal Government. Some of these sites were established as far back as the 1930's. In 1978 Alberta Environment took over the mountain snow survey network and added a number of courses to get better coverage with respect to area and range in elevation. The development of data collection platforms (DCPs) and satellite communication in the 1970's provided the means of obtaining data on a near real time basis from virtually any point in the Province. In 1978, the Alberta Environment River Forecast Centre (Graham and Kuhnke, 1978) produced a major proposal to upgrade the precipitation and climate network of the headwaters of the South Saskatchewan Basin. As the main purpose of the new network is to support flood and water supply forecasting needs, all 26 precipitation stations and the 12 climate (multi-parameter) stations are equipped with telemetry capable of transmitting data on a near real-time basis. In the case of the remote mountain sites telemetry could be provided most economically by the use of satellite communications. In 1979 the network upgrading proposal was accepted and work began immediately.

Instrumentation used to monitor snow

For any snow data collection system to be useful for forecasting purposes, the data must be available in near real time. Conventional snow courses are very expensive to operate particularly in remote mountain areas where helicopters are the only means of access. It is not economically feasible to carry out snow surveys more frequently than once per month. Therefore, it was decided to include snow monitoring equipment at ten climate (multi-parameter) sites. The locations of the sites were chosen taking into account exposure and local ground conditions. It was considered important to have an even geographical distribution of stations from north to south throughout the basin. Some of the sites are located along the continental divide with others along the front and middle ranges. The elevation of the sites varies between 1800 and 2300 metres. See table 1 and figure 1 for locations and further details. As of March 1985, eight of the stations were in full operation and the other two are expected to be completed this summer.

Nine of the ten proposed stations were located in the mountains far from telephone lines or observers. After careful study of the communication alternatives it was decided to use the Geostationary Orbital Environmental Satellite (GOES) system . The first data collection platforms (DCPs) using the GOES system were installed in 1980 and have been extremely reliable. In 1981 for example, eight precipitation stations operated for the full twelve months. Of the 209,646 pieces of data expected for the period, 98.7% were received. The missing data included all losses due to failure of sensors, equipment and line losses between Edmonton and Wallops Island, Virginia (Coles and Graham, 1983). The tenth station located at Sunshine Village ski resort near Banff was installed in cooperation with Parks Canada and forms part of their avalanche warning system. This station uses telephone lines to transmit the data from Sunshine Village to Banff.

The data collection platforms are powered by twelve volt batteries, recharged by vertically mounted solar panels. Mounting the panels vertically minimizes the build up of ice and snow and guarantees a power source even during the coldest parts of the year.

Each of the ten climate sites are equipped with sensors to monitor precipitation, temperature, and the water equivalent of snow on an hourly basis. Some of the sites also have wind and humidity sensors (See table 1).

The instrument used to measure melt rate and snow water equivalent is the snow pillow. The pillows used by Alberta Environment are 3 metre diameter hypalon pillows manufactured by the Water Saver Company of Denver (See figure 2). The pillow is filled with approximately 1200 litres of a solution consisting of 50% water and 50% methyl alcohol. The pillow is connected directly to a stilling well by means of 19 mm diameter polyethylene tubing. The level in the 20 cm diameter stilling well varies in direct proportion to the amount of pressure exerted on the pillow by the weight of the snow. The changes in level in the stilling well are monitored continuously by a Leupold & Stevens A71 water level recorder. The readings after adjustment for specific gravity provide a continuous historic record of the snow water equivalent. A Baldwin optical encoder working in parallel with the Stevens recorder translates the hourly readings (measured to the nearest millimetre) into binary coded decimal data (BCD). The data are then transmitted every three hours to Wallops Island, Virginia via the GOES system. The data are retrieved automatically by phone at pre-determined intervals which can be changed as required.

Siting and Installation Problems Associated with Snow Pillows.

Siting is the single most important factor to be considered when installing snow pillows. Because the cost of the hardware and its installation is so high, the site chosen should be close to ideal. The 1985 capital cost of a snow pillow with telemetry and sensors to measure precipitation, temperature, humidity and wind is approximately $25,000.00. The cost of installing the station depends on the difficulty due to the individual site and the amount of helicopter time required. Installation costs in Alberta including wages, expenses and miscellaneous materials have ranged between $10,000.00 and $20,000.00.

General guidelines are available (Farnes, 1978) on locating a single snow pillow in a basin. The snow pillow should be installed in a sheltered area near the mean water-producing elevation of the basin. If the pillow is located too low in the basin the snow on the pillow will be depleted before the peak runoff in the basin occurs. Also the amount of snow accumulated on the pillow will be much less than the average snow water equivalent for the basin. On the other hand if the pillow is located at too high an elevation in the watershed, melt will not occur until after the main runoff has taken place at lower elevations. Several pillows located at various elevations within a sub-basin would be ideal, however, the cost of installing several pillows could not be justified.

TABLE 1

ALBERTA ENVIRONMENT

INVENTORY OF MOUNTAIN SNOW PILLOWS

NAME	BASIN	LOCATION LATITUDE	LOCATION LONGDITUDE	ELEVATION (metres)	ADDITIONAL SENSORS	YEAR TELEMETRY ESTABLISHED
Akamina Pass	Oldman	49° 01' 40"	114° 03' 10"	1800	P.T.W.H.	1981
Gardiner Creek	Oldman	49° 21' 40"	114° 30' 57"	1920	P.T.W.H.R↓R↑.	1983
Limestone Ridge	Red Deer	51° 53' 19"	115° 23' 04"	1950	P.T.W.H.	1982
Little Elbow Summit	Bow	50° 42' 20"	114° 59' 20"	2120	P. & T.	1979
Lost Creek	Bow	50° 10' 26"	114° 42' 36"	2130	P.& T.	1985 (Sept)
Racehorse Creek	Oldman	49° 49' 17"	114° 37' 19"	1920	P.& T.	1983
Skoki Mountain	Red Deer	51° 32' 26"	116° 03' 23"	2040	P.& T.	1981
*Sunshine Village	Bow	51° 04' 43"	115° 46' 48"	2200	P.& T.	1981
Three Isle Lake	Bow	50° 37' 53"	115° 16' 46"	2240	P.T.W.H.	1983
Odlum	Bow	50° 29' 10"	114° 54' 26"	2060	P.T.H.	1985 (Sept)

P - Precipitation
T - Temperature
W - Wind direction & velocity
H - Relative humidity
R↓ - Radiation (Incoming) R↑ Radiation (outgoing)
* Located at Parks Canada Installation

Once the general location of the site has been selected the specific site must be chosen. The State of California (1976) and Cox (1978) provide detailed guidelines on this topic. The main points to be considered are the following:

1. Snow pillows should be located in a clearing in the trees, small enough to minimize drifting. However, the trees should not be so close that they influence the snow accumulation by forming a canopy or cause melt due to long wave radiation.

2. Pillows should be located on level ground to prevent creep and drainage problems, but the pillow should be at a slightly higher elevation than the instrument house (see figure 2).

Extreme care when installing pillows is imperative. If the pillow is not properly installed, malfunctions will occur and no useful information will be obtained for the season. Once the pillow is covered by snow it is virtually impossible to make repairs to the system.

The most common problems to be aware of are as follows:

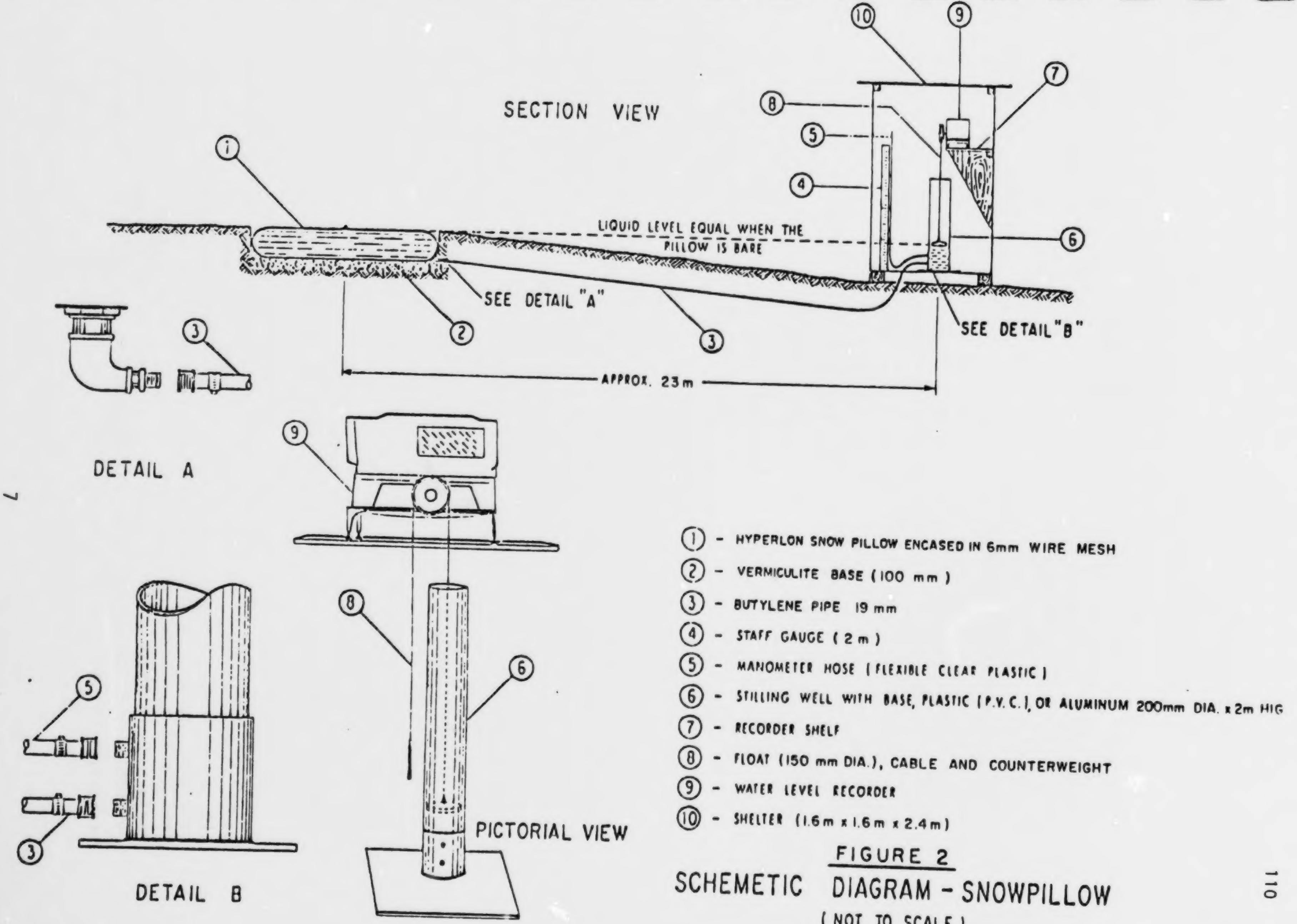
1. Leaks in pipes and fittings: Even the smallest leak can drain the pillow and cause complete loss of record.

2. Puncturing of pillows: The ground beneath the pillow must be flat, and clear of any debris which might puncture the pillow. The base should be covered with a clean material such as sand which can be levelled with ease.

3. Damage to the installation by rodents: Rodents tend to eat the pipe fittings and even the pillow itself. Damage can be minimized by covering the pillow with 6 mm hardware cloth.

4. Air locks in the system: A certain amount of air may be introduced into the system when filling with the methyl alcohol solution. A vacuum pump is used to remove all air from the pillow. Care must also be taken to avoid any air locks between the pillow and the stilling well.

5. Destruction of pillows by wildlife: The sharp hooves of deer, moose or elk can easily puncture the pillow. Sites should be fenced to deter such animals. (Unfortunately fencing is not always effective, as the Little Elbow pillow was punctured earlier this winter). In Montana and British Columbia, where bears are a major problem, pillows are completely covered with a light gauge metal sheeting.


SECTION VIEW
LIQUID LEVEL EQUAL WHEN THE PILLOW IS BARE
SEE DETAIL "A"
SEE DETAIL "B"
APPROX. 23m
DETAIL A
DETAIL B
PICTORIAL VIEW
①
②
③
④
⑤
⑥
⑦
⑧
⑨
⑩

① - HYPERLON SNOW PILLOW ENCASED IN 6mm WIRE MESH

② - VERMICULITE BASE (100 mm)

③ - BUTYLENE PIPE 19 mm

④ - STAFF GAUGE (2 m)

⑤ - MANOMETER HOSE (FLEXIBLE CLEAR PLASTIC)

⑥ - STILLING WELL WITH BASE, PLASTIC (P.V.C.), OR ALUMINUM 200mm DIA. x 2m HIG

⑦ - RECORDER SHELF

⑧ - FLOAT (150 mm DIA.), CABLE AND COUNTERWEIGHT

⑨ - WATER LEVEL RECORDER

⑩ - SHELTER (1.6m x 1.6m x 2.4m)

FIGURE 2

SCHEMETIC DIAGRAM - SNOWPILLOW

(NOT TO SCALE)

FROM: KERR (1976)

Operational problems associated with snow pillows

Most problems associated with the operation of snow pillows can be eliminated by the use of proper installation techniques and careful maintenance. However, there are some problems inherent to the system which should be recognized, otherwise serious errors can be made in the interpretation of the data obtained from the pillow.

Bridging of the pillow commonly occurs when precipitation falls as rain or when a melt period is followed by a severe cold spell. The bridge formed by ice layering in the pack prevents the full weight of snow on the pillow from being transmitted to the stilling well and results in an undermeasurement of the snow water equivalent. Checking the accumulation in the precipitation gauge against the snow pillow indicates if such a condition exists. In Alberta, bridging has been found to be a common phenomenon in the shallow plains snow pack, but seldom occurs in the mountains. The condition can sometimes be relieved by walking around the perimeter of the pillow, thereby breaking the "bridge" that has formed.

Several studies (State of California, 1976) have indicated that there is a lag between the time the snow falls, and the time the recorder fully registers the event. Careful comparison with precipitation gauge data in Alberta has revealed that lags do occur after major snow falls, but they have been usually measured in hours rather than days.

Just before melt occurs quite drastic diurnal fluctuations often occur in many snow pillow plots. A sudden drop in pressure is indicated around mid-morning and the trace in the pillow then recovers slowly reaching a maximum around mid-night. The reasons for these diurnal fluctuations are not fully understood. The fluctuations are not solely temperature dependent, but occur only in the early part of the melt season. It appears the fluctuations are due to structural changes that take place in the pack caused by variations in temperature and short wave radiation. It is interesting to note that when melting has relieved the internal stresses, the diurnal fluctuations disappear and the pillow operation returns to normal. Diurnal fluctuations are much more common in shallow snow packs on the plains then they are in the mountains. They are also more prominent on clear sunny days. The problem of interpreting the data when diurnal fluctuations occur is overcome by using a reading at a time when the pillow is stable. The Alberta Environment River Forecast Centre uses the 6:00 a.m. reading as the value for the day.

At higher elevations drifting due to winds is difficult to predict. At Gardiner Creek, the site was selected in the late spring and the station was installed the same summer. It did not appear that wind would be a problem. However, high winds this winter have caused serious drifting and the results from the pillow have been erratic. The policy now is to run a conventional snow course for at least one full winter before deciding on a pillow installation site. In this manner, it should be possible to detect potential problems before committing to a permanent installation.

Comparison of snow water equivalence data collected from snow pillows and standard snow courses

One of the reasons for installing snow pillows is to reduce or eliminate the number of costly visits that have to be made to measure the standard courses, the eventual goal being to eliminate the need for certain snow courses all together. At some snow pillow sites there are adjacent snow courses which have many years of record. Data from these courses are often used as indices in streamflow forecast models. For this reason it is necessary to relate snow course data to that obtained from the snow pillow.

The method used in Alberta to calibrate the pillow to the snow course is a method suggested by the United States Soil Conservation Services (1972). Over a period of at least three years the ratio of snow course to snow pillow reading for concurrent dates is obtained and a mean value calculated. As long as the variation from the mean of the ratios is not more than plus or minus 0.05, the pillow record is considered to duplicate the snow course record. In the Alberta experience, the relationship between the pillow and the courses does not always meet the criteria described above, and it has been necessary to develop a new index based solely on continuous pillow readings. This may be due to the fact that the snow courses (comprising the average of ten separate point measurements) were established before the snow pillow location was determined. It is now standard practice at each site visit to obtain readings from the old snow course and adjacent to the pillow. Figure 3 illustrates the relationship between pillow and snow course readings in 1982/83 at Little Elbow Summit.

Comparison of precipitation data collected by snow pillow sensors and the Fisher Porter precipitation gauges.

It has been well documented (Goodison & McKay, 1972) that the Fischer Porter automatic gauge under catches snow particularly in areas exposed to wind. As mentioned previously the Alberta snow pillow sites are for the most part well sheltered. Generally, the accumulation of precipitation measured in the Fischer Porter gauges and that measured by the pillow compare favourably. The two values are plotted throughout the winter, and any significant deviation from one to the other usually indicates a problem has occurred or that the precipitation is falling as rain.

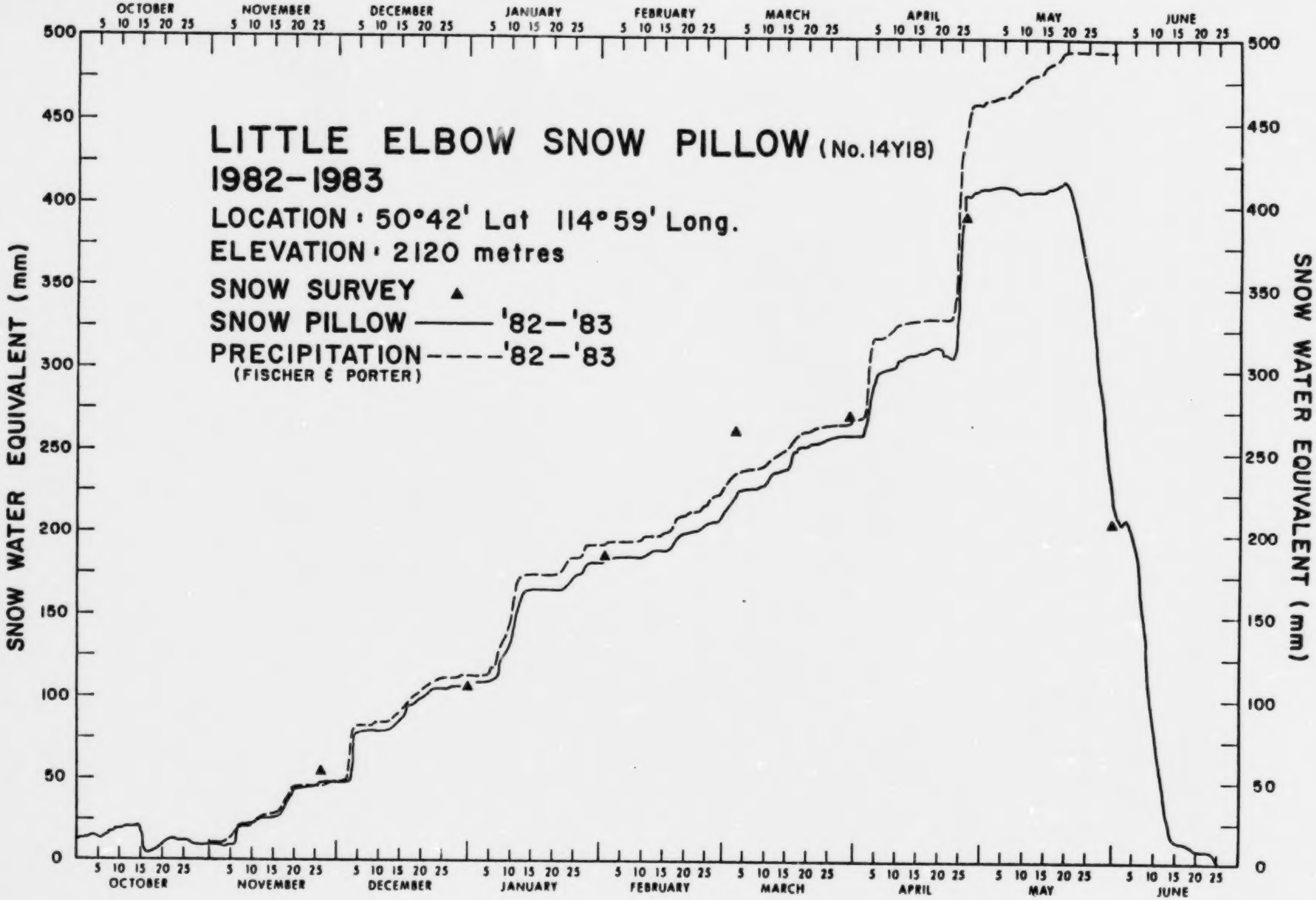

LITTLE ELBOW SNOW PILLOW (No. 14Y18)
1982–1983
LOCATION : 50°42' Lat 114°59' Long.
ELEVATION : 2120 metres
SNOW SURVEY ▲
SNOW PILLOW —— '82–'83
PRECIPITATION ---- '82–'83
(FISCHER & PORTER)
SNOW WATER EQUIVALENT (mm)
0
50
100
150
200
250
300
350
400
450
500
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
5 10 15 20 25

FIGURE 3

An example of the type of problem that has been noted on several occasions is "capping" of the Fischer and Porter gauge. When the snow fall is wet and sticky (condition that occurs quite often in Southern Alberta), the snow clings to the side of the gauge eventually forming a cap. The cap prevents any more precipitation from entering the gauge. If the temperature should rise above freezing, the cap falls into the gauge and normal operation resumes. It is only with telemetry, the presence of a snow pillow, and a Fischer Porter gauge that this undercatchment can be quantified. In the standard networks which do not have telemetry this phenomenon can go undetected, as the period between visits is often several months.

Heavy rain on snow often results in a dramatic (although sometimes short lived) drop in pressure (Buer et al, 1984) on the snow pillow. Comparison of the snow pillow data with the Fischer Porter data and temperature often confirms that a rain event had taken place. The form in which precipitation falls, snow or rain, is extremely significant to the forecaster, for rain on snow can cause rapid melt.

The primary purpose of the snow pillow is to measure snow accumulation and melt rates whereas the main reason for the Fischer Porter gauge is to measure summer rainfall. However, the experience gained operating both types of sensors in real time during the winter indicates that inconsistencies in performance is due to specific physical conditions and the operation of the dual system of sensors in the winter is well worth while.

How snow pillow data have been used

1. Snow melt rates during the critical spring and early summer period can be fed directly into runoff simulation models. A modified version of the Streamflow Synthesis and Reservoir Regulation (SSARR) model is used to predict mountain runoff in Alberta. A melt rate index is necessary to simulate snow melt runoff with the model. Melt rates from snow pillows are calculated for individual basins. Studies by Ferner & Wigham (1985) have shown that snow pillows in the Marmot Research Basin provide better melt rate estimates for application to SSARR than indirect methods that use temperature and other parameters.

2. To carry out long range water supply forecasts, the daily accumulation of snow obtained from pillows is input to simulation models which are constantly updated. Snow pillows provide a method to constantly update this information, particularly after major storms.

3. Snow pillows provide a reliable estimate of snow accumulation from the start of the runoff season throughout the active period. If the models are deviating too much from the observed snow available, they can be corrected as needed.

4. For flood forecasting in the spring, data from the pillows are used to detect if precipitation is falling in the form of snow or rain.

5. Snow pillows can be used to estimate the date of the peak flow for specific streams. For example, a straight forward way of predicting peak dates using snow pillow data in the Western U.S. has been described by Farnes, (1984).

In the Western United States (Farnes, 1985) where extensive snow pillow networks have been used for many years, pillows are being used for purposes other than those related to water resources. Snow pillows can be used in the management of parks and wildlife. For example, they can give useful information with respect to back country travel, can be used to tell how much snow is on the ground at higher elevations, and whether the snow conditions are ripe for avalanches. Pillows can also be used to help predict when bears may emerge from hibernation, for a good correlation appears to exist between the start of melt and the beginning of bear movements.

In Montana the pillows are also used to help manage remote mountain highways. From a base camp, managers can determine if they need to plough roads and in what order the work should be done. It is believed that in the future, further applications for snow pillow data will be found.

Conclusions

1. Snow pillows in the mountainous areas of Alberta monitored in near real-time and used in conjunction with other meteorological sensors provide valuable information for streamflow forecasting.

2. The successful operation of snow pillows depend on good installation and maintenance practices. Data from the pillow and other sensors must be inspected and evaluated on a ongoing basis to obtain maximum benefit from the information provided.

3. Since winter precipitation may fall either as snow or rain, it is desirable to run a precipitation and temperature gauge in conjunction with the snow pillow at key sites. Anomalies in the performance of these sensors that may normally go undetected can be found by closely monitoring the data from the two different types of sensors.

4. Snow pillows are not the ideal snow monitoring device for they are expensive to install, and they have inherent weakness in operation which are sometimes difficult and even impossible to overcome. They are also prone to destruction by several forms of wildlife. New devices such as the nuclear snow gauge look promising and their performance should be investigated for the forecasting networks of the future.

5. Melt rates provided from strategically placed snow pillows give an index that when used in the SSARR model results in better forecast estimates than using an index based solely on temperature.

6. There are potential uses for snow pillows that go beyond the water resource management field. Some of these are avalanche prediction, wildlife management, and general park management.

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AGENCY REPORTS

ATMOSPHERIC ENVIRONMENT SERIVCE

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Scientific Services Division

The total number of climatological stations remained basically unchanged between January 1984 and May 1985. A total of 13 new stations were added to the AES Western Regional Network while 17 stations were closed. The observing program was expanded to include both temperature and precipitation at four locations. A list of additions, deletions and program changes is attached.

NEW CLIMATOLOGICAL STATIONS - WESTERN REGION
January 1984 to May 1985

New Stations	Basin	Latitude	Longitude	Program
Beiseker Village	Red Deer	51°23'	113°32'	P
Calgary Springbank A	S. Sask.	51 06	114 22	PT
Carstairs West	Red Deer	51 34	114 17	P
Craigmyle	Red Deer	51 46	112 17	P
Edmonton Villeneuve A	N. Sask.	53 40	113 52	PT
Hackett	Red Deer	52 09	112 28	P
Leduc	N. Sask.	53 09	113 41	P
Macpherson	YT	60 49	135 13	PT
Morley River	YT	60 01	132 10	PT
New Brigden East	N. Sask.	51 40	110 16	P
Quill Creek	YT	61 27	139 15	PT
Rimbey	Red Deer	52 38	114 14	P
Sundre	Rocky Mtn.	51 45	114 47	P

Station Closures	Basin	Latitude	Longitude	Program
Bluffton	Red Deer	52 45	114 17	P
Bob Creek	Rocky Mtn.	49 53	114 15	PT
Buffalo	Red Deer	50 56	110 56	P
Dewinton	S. Sask.	50 48	114 02	P
Dowling Lake	Red Deer	51 45	111 55	P
Gooseberry Lake	N. Sask.	52 07	110 42	P
Horseshoe Lake	N. Sask.	52 21	110 44	PT
Hudson Bay Mine	YT	63 11	130 10	PT
Kluane	YT	61 01	138 24	PT
MacPass A/Strip	YT	63 11	130 11	PT
Manville South	N. Sask.	53 06	111 21	P
Pinedale	Atha.	53 34	116 06	P
Pothole MacIntyre	Milk	49 13	112 51	P
Shalka Lake NE	N. Sask.	51 52	112 01	TP
Sunnynook	Red Deer	51 14	111 39	P
Two Pete Creek	YT	62 38	135 42	PT
Wood House	S. Sask.	49 57	113 22	P

Program Changes	Basin	Latitude	Longitude	Program
Arneson	Red Deer	51 14	110 03	P to TP
Craigmyle	Red Deer	51 46	112 17	P to TP
Hackett	N. Sask.	52 09	112 28	P to TP
Sundre	Red Deer	51 45	114 47	P to TP

The following special reports and climatological studies were undertaken by Scientific Services personnel:

Climate of Calgary - draft
Climate of Edmonton - completed
Climate of Kananaskis - completed
Station Climate Digest - Banff - completed
Station Climate Digest - Jasper - completed
Station Climate Digest - Calgary - under preparation
Marmot Creek Watershed Research - on-going
Lesser Slave Lake Area Storms - Summer 1983 - completed
Smoky-Peace River Basin Studies 1983 - completed
Alberta Rainstorms - Summer 1984 - completed
Review of Snow Chemistry Sampling and
   Analysis Procedures in Western Canada - completed
Break-up Pattern over Southern Beaufort
   (Artificial Islands) - on-going
Non-Standard Arctic Data Catalogue - final draft
Arctic Wind Assessment Project - final draft
Manual for Precipitation Chemistry
   Sampling on Event Collection Basis - completed
Estimate of Sulphate Deposition on
   Precipitation for Alberta - completed
Report on Sulphate Deposition in Western Canada - completed

AES is participating in the instrumentation and collection of climatological data for the 1988 Winter Olympic sites at Mt. Allan and Paskapoo. Personnel also provided assistance in setting up meteorological instrumentation on an Ice Island at 82N 93W.

Report of Agriculture Canada - Soil Survey to the Alberta Climatological Association

J. Tajek; June 1985

Climatological data are used by soil survey for:

a) general characterization of climatic condition of an area.
b) interpretation of soil survey data for agriculture and other users, or for modelling.

A. The soil survey of Cardston County was completed and report compiled. The mean annual temperature, m.a. precipitation, frost free days and other data were used to characterize the climatic condition. In addition some soil temperature data were collected.

B. The Universal Soil Loss Equation was used to compute the potential erodibility of soil in the area covered by SIDMAP database. In the course of this work new rain erosivity values (RT) were calculated for 25 stations equipped with bucket rain gauges. The 2 years, 6 hours rain intensity values used for calculation were supplied by AES Edmonton. New RT values include contribution of spring runoff calculated from snow on the ground and snow course data provided by AES.
Aridity index values for Warner and Newell counties were calculated. These values were based on soil water holding capacity and the annual water budget for alfalfa as computed by Sly. In addition water storage data for various soils in Peace River area were supplied to Alberta ENR for their evaluation project.
The main problem encountered by soil survey in the use of climatic data was the low density of network, mainly those stations recording rain intensity. For future work in modelling of erosion, aridity or crop yield, probability of occurrence of individual climatic events will be required.

AGRICULTURE CANADA RESEARCH STATION - BEAVERLODGE

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TOH OCO

The Agrometerology program at the Beaverlodge Research Station continues to operate both a cooperative and explicit Research program as well as including extension and data collection activities.

Data acquisition and analysis activities have recently been significantly aided by the purchase and installation of our own, in house, VAX 11/730 based computer system. This is a major advancement over the previous use of datapac to Ottawa and, it is hoped that this system will allow us increased flexability with respect to data collection options as well as the capability to compile and analize large sets of meteorological data that were previously beyond our capabilities. Coupled with this installation we hope to be able to both replace our existing data acquisition system at Beaverlodge as well as complete this installation of the automated equipment at Fort Vermilion Experimental Farm that was mentioned in last years report.

During the past year there have been several changes in the support personnel associated with this program as well as one co-operating research scientist who has accepted a new position with Alberta Agriculture in Fairview. Despite this the cooperative work on the Canola Root Rot complex which was started last year is continuing. This work has been expanded to cover approximately 20 sites within the southern half of the Peace River Region.

Data collection aimed at providing a quantification of the Radiation balance for Beaverlodge is also continuing with the existing data sets being edited and compiled onto the new computer. Another program which is also continuing involves a study of the effects of low soil temperature on the germination and emergence of Canola which is partly funded under the Alberta Agriculture, Farming for the Future program. This program is now into its second year and is providing significant insight into the topic area. Since soil moisture continues to be a major agricultural concern we are continuing a monitoring program in this area which we hope will provide us with a sound basis on which to conduct further more detailed studies in the future. Related to this is a study examining moisture use by various crops as well as fallow conditions and the herbicide efficacy or dandelions under differing soil moisture stess levels. Additional co-operative work is also continuing in the area of meteorological effects on plant pathology with particular emphasis on leaf stripes of Barley and Fescue as well as the damping off complex's attacking winter wheat. Finally during the last year considerable work has been expended with respect to the formulation of a new set of criteria for the assessment of the climatic resources for agriculture across the province. It is hoped that these criteria will be finalized in the near future and will be available for land classification projects.

PUBLICATIONS:

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NORTHERN FOREST RESEARCH CENTRE

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Recent Activities

Wetlands and climate

A map of the climatic ecoregions of Canada is being finalized by the Ecoregions Working Group (Canada Committee on Ecological Land Classification) under the chairmanship of S. C. Zoltai. There are 65 regions, each characterized by climax (stable) vegetation on normal (not too dry or wet; not infertile or toxic) soils. By eliminating the local effects of soil differences, the stable vegetation is believed to express the influence of climate on vegetation development. These regions should provide areas within which plant development following disturbances (fire, cutting, etc.) should be similar on similar soils. The map (1:7M) is now finalized, and the brief descriptions of each region is now in the final review process. The map and text is being prepared for inclusion in the National Atlas of Canada.

A study of wetland drainage is being initiated, with sites near Mclennan, Edson, and Slave Lake. Ditching will be done to improve drainage and enhance tree growth on peaty and mineral wet soils. Each site will be instrumented for soil and air temperatures at several levels, precipitation, relative humidity and water table fluctuations at different distances from drainage ditches.

The temperature and precipitation data for 62 stations in predominantly forest, 27 in forest-grassland and 12 in forest-tundra (north to south) transition were examined for evidence of climatic change. The predominantly forest region showed an average rise of 0.019 °C per year from 1880 to 1981 (statistically significant at $P<.01$). Smaller changes of 0.012 °C and 0.014 °C per year during the same time period were noted for the forest-grassland and forest-tundra regions (statistically significant $P<.05$).

Two recording precipitation gauges are being installed in 1 acre clear-cut blocks in aspen forest near Calling Lake and Kinuso. The data from these gauges will be used to gather information on the input of nutrients (N,P,K,Ca,Mg and S) following clear-cutting. This information will be used primarily for calibrating a model of nutrient cycling in aspen. Other data being gathered are litter decay rate, nutrient release and mobility from the root zone.

Fire

A joint CFS/Alberta Forest Service experimental burning project in the black spruce-cladonia-Labrador tea fuel complex was initiated during the 1984 fire season. Inclement weather prevented any fires from being conducted in 1984; the project will continue into 1985.

Work continued on the development of the Canadian Forest Fire Danger rating system; the 4th edition of the tables for the Canadian Forest Fire Weather Index System were published and an interim edition of the user guide to the Canadian Forest Fire Behavior Prediction System was released for field trials. Two half-day fire weather seminars were organized. A PRUF project with the University of Alberta's Department of Geography, (Meteorology Division) is being undertaken, with CFS support, on the "Climatology of atmospheric conditions related to extreme forest fire behavior in West-Central and Northern Canada."

Forest hydrology and microclimate

The microclimate of 1, 3 and 5 tree-height diameter forest clearings was monitored during the past winter. Fourteen sites were instrumented with wind, net radiation (all wave), relative humidity, air and snow temperature sensors. In addition, snow evaporation was monitored for selected time periods by weighing small pans. Preliminary results indicate that evaporation from snow is small as long as wind speed near the ground is low. Most of the incoming energy causes melt -- even in January.

Weather and snow data for Marmot Experimental Watershed (Mount Allan) were in high demand this past year. The data from the 4 permanent stations that are operated by the Canadian Forestry Service are now available in IBM-PC format suitable for direct entry into Lotus 1,2,3. We expect to have these data on MTS files at the University of Alberta before the end of 1985.

A computerized version of a procedure to predict annual water yields from harvested or natural forested areas is on line at the University of Alberta. This program uses a set of climatically similar zones, forest cover type and local precipitation to provide estimates of annual water yields that are generally within 10% of actual. Those who have access to the U of A facilities can use this self-prompting program by typing $RUN VSAS:WRENSS (Basic familiarity with forest hydrology principles is assumed.). A compiled version is also available for the IBM-PC.

Toxic substances

Results are being synthesized from a study that was designed to describe the variability in the amount of precipitation and chemistry of nutrient and pollutant deposition (dry and wet) within a lodgepole pine forest in the foothills of Alberta. Coefficients of variation in chemical measurements were high and depended upon microenvironment (micro-scale canopy characteristics), time of year and the element under consideration. Estimates of the number of samples that are required to accurately describe the chemical composition of throughfall in this forest type are being made. In addition, the amount of difference in pollutant deposition that must occur between sites before significance can be determined will be evaluated.

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ALBERTA AGRICULTURE
AGROMETEOROLOGICAL HIGHLIGHTS

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1. FUNDING

Alberta Agriculture has continued to fund research in weather modification, hail supression and snow augmentation by Alberta Research Council. Also, funding of research through "Farming for the Future" has continued by which some projects with Agroclimate components have been done.

2. IRRIGATION AND CONSERVATION DIVISION ACTIVITIES

The Conservation & Development Branch has continued to provide weather and climate information to the department staff and others through the Agwx bulletin, the annual fall stubble soil moisture map and consultative activities. A publication on precipitation probabilities is being prepared for 78 Alberta Stations for periods of the year of interest in crop production (such as May 1 to July 31).

A proposal to improve both the timelines and availability of current weather information and forcasts to agribussiness has been developed. This will feature a phone in system funded by Alberta Agriculture with information provided and updated three times a day by Atmospheric Environment Service (AES). It is patterned after Manitoba's successful system. Alberta Agriculture has co-operated with AES in the further development of the agriculture weather forcast by assisting in identifying information needs through several follow-up surveys.

The Conservation and Development Branch, because of the severe soil erosion cuased by the wind in the southern part of the province during later 1984 and early 1985, has commenced studies of the effect of wind on this process. Also a consulting firm has been employed to study methods to measure and map the damage.

The Drainage Branch has continued their studies with a number of wind mills for the purposes of pumping water. Data is being collected to evaluate both the environment and the equipment.

The Irrigation Branch continues to collect meteorological data as it relates to irrigation water management and to provide it to individual users.

3. PLANT INDUSTRY DIVISION

The Plant Industry Division continues its studies in weather and climate as they relate to insect development and control. Wind and its effect on spraying remains an interest.

4. THE AGROMETEORLOGY ADVISORY COMMITTEE

This Alberta Agriculture Committee continues to provide a forum for information exchange, needs and a means of communicating weather and climate information needs to the Department, Agriculture Canada, Alberta Universities and the National Agrometeorlogical Expert Committee. The Weather Services sub-committee continues to define the weather needs of Agribusiness and in assisting the design of services to meet these needs.

An agriculture climate rating working group was formed to assist the Soil Rating Group in defining climate parameters to rate land for agricultural use. Such a system is being developed.

5. CLIMATE CHANGE

Alberta Agriculture has formed a committee with Alberta Energy and Natural Resources to look at climate change in the provincial context.

ALBERTA FOREST SERVICE
ENERGY AND NATURAL RESOURCES
EDMONTON, ALBERTA

1. The Lightning Location and Protection System (LLP) is being integrated with N.W.T. and B.C. The Atmospheric Environment Service is installing a RDP drop onto the system.

2. Some of our ranger stations are no longer reporting weather and some are reporting only during the spring season.

3. There has been no change to our automatic stations that report through GOES other than the addition of pressure sensors to two stations.

4. We are acquiring more FTS type fire weather stations.

5. There is continuing cooperation with the AES in which they assume the cost of operating several of our ranger climate stations during the winter.

6. We continue to provide lookout and ranger station weather data to the AES for publication in the monthly record of meteorological observations in Western Canada.

7. We are making increased use of Sacramento gauge data to determine drought code starting values. We may install Sacramento gauges at a few of our lookouts in areas where winter precipitation reports are sparse.

ALBERTA HAIL AND CROP INSURANCE CORPORATION

I.S. Selirio
Bag Service #16
Lacombe, Alberta

Grain Crops

Drought, hail, grasshoppers, even excess spring moisture in some places and early onset of winter all contributed to the unusually heavy crop losses in 1984. Payments under the Canada-Alberta Crop Insurance program for major crops exceeded $200 million, more than three times the previous record, which used up all the 1984 premiums plus all the reserves accumulated over the past twenty years.

Hay and Pasture Crops

Drought in southern and central regions of Alberta resulted in heavy payouts under the Canada-Alberta Crop Insurance program for hay and pasture crops. Payments amounted to $3,862,309 which is 2.54 times the total premium or just over five times what the farmers paid in premiums.

Under this program, yield of each participating farmer is calculated using the farmer's rainfall records and weather data from the closest weather station. In 1984, 1107 farmers provided daily rainfall reports during the period May 1 to August 31. The Atmospheric Environment Service provided daily climatological reports from all available stations during the period April 1 to October 31. Soil moisture observations were conducted on about 100 farms in late April and on about the same number of sites in early June. Actual yield clippings were conducted on about 140 hayfields in early July.

The area eligible for insurance in 1984 included the following: Counties of Beaver, Camrose, Flagstaff, Lacombe, Minburn, Paintearth, Ponoka, Red Deer, Stettler, Vermilion River and Wetaskiwin; I.D.'s 5, 6, 8 (south of the Bow River) and 10; M.D.'s of Acadia, Cardston, Foothills, Pincher Creek, Provost, Wainwright and Willow Creek; and Special Areas 2 (north of the Red Deer River), 3 and 4. The same area is eligible for insurance in 1985.

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Forage Research

A project to quantify the effects on production of various degrees of soil moisture stress, high temperature, and high evaporative demand commenced in 1984 in cooperation with Alberta Agriculture. In Brooks, one-year old plots of alfalfa, brome, crested wheat grass and alfalfa-brome were harvested every week. Three water regimes were imposed during the first growth period and again during the second growth period following each of the three initial moisture regimes. In Lacombe, one-year old plots of alfalfa, brome, crested wheat grass, red clover, alfalfa-brome and alfalfa-crested wheat grass were harvested also but under dryland conditions. Phenological and soil moisture observations were conducted every week at both locations. In 1985, measurements will continue on these plots and on a new set of one-year old plots.

Field Hay Drying

Field measurements of hay drying continued in 1984 at 9 sites in west central Alberta. Moisture contents of hay swaths were determined starting at the time of cutting and every day thereafter until hay was baled. In early July 1984, hay was baled 1 to 2 days after cutting. However, cut-hay that was rained on at least once (1.3 to 22.0 mm) required an additional 2 to 4 days of drying. The project will continue in 1985. The objective is to assess under Alberta conditions, weather-based simulation techniques that predict hay drying for possible applications in hay quality insurance.

Publication

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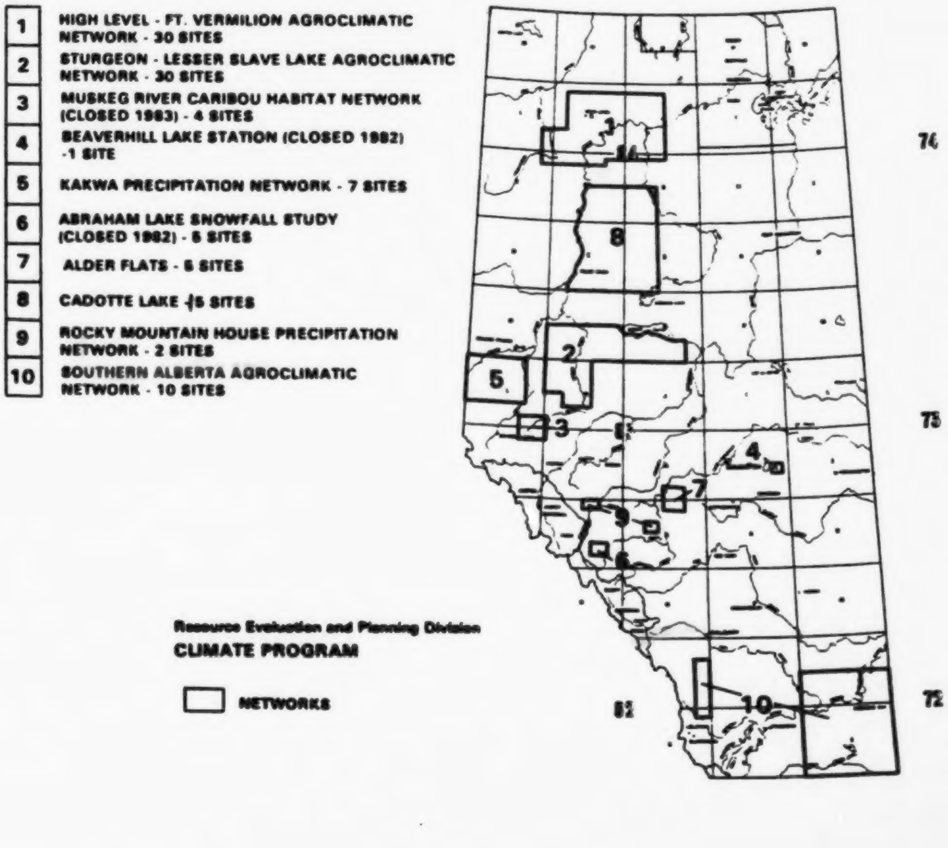
Alberta Energy & Natural Resources
Resource Evaluation & Planning Division

Serge Dupuis

The division archives daily data for more than 100 sites in 10 special networks (Fig. 1). The data has been merged with existing AES and AFS data for special studies and is available in standard DLY04 format as defined by AES.

Province-wide low resolution 1:2 million maps of selected parameters are under preparation. Detailed maps of the Fort Vermilion Network are being published for support of agricultural land allocation.

A comprehensive station catalog has been compiled to assist in climate studies across the province. The database extends the current AES directory to include most data gathering agencies in the province.


1 HIGH LEVEL - FT. VERMILION AGROCLIMATIC NETWORK - 30 SITES
2 STURGEON - LESSER SLAVE LAKE AGROCLIMATIC NETWORK - 30 SITES
3 MUSKEG RIVER CARIBOU HABITAT NETWORK (CLOSED 1983) - 4 SITES
4 BEAVERHILL LAKE STATION (CLOSED 1982) -1 SITE
5 KAKWA PRECIPITATION NETWORK - 7 SITES
6 ABRAHAM LAKE SNOWFALL STUDY (CLOSED 1982) - 5 SITES
7 ALDER FLATS - 5 SITES
8 CADOTTE LAKE - 15 SITES
9 ROCKY MOUNTAIN HOUSE PRECIPITATION NETWORK - 2 SITES
10 SOUTHERN ALBERTA AGROCLIMATIC NETWORK - 10 SITES
Resource Evaluation and Planning Division
CLIMATE PROGRAM
NETWORKS
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ENVIRONMENTAL PROTECTION SERVICES
Alberta Environment

Bonnie L. Magill
Research Management Division

During 1984, Alberta Environment continued to support research and monitoring activities related to air quality and meteorology. In addition to ongoing studies, a review and synthesis or urban air quality research in Alberta was undertaken in the context of national and international research activities. The subsequent recommendations for research formed the basis for an urban air quality/climatology research program. The program was designed to (1) characterize urban air quality and (2) delineate and understand the consequences of urban air pollution. The climatology subprogram will be designed to optimize the use of climate information to examine probable climatic effects on the environment. This subprogram is supportive and complementary to the Canadian Climate Program as recommended by the Canadian Council of Resource and Environment Ministers. The department provides the lead role and chairs the Alberta Climate Advisory Committee.

An Energy Resources Conservation Board Inquiry into the 1982 Lodgepole Sour Gas Well Blowout addressed many scientific issues: health effects of hydrogen sulphide, monitoring methodologies and strategies, diffusion and deposition calculations, and effects on soil, vegetation, and animals. Other projects included: (1) updating the provincial inventories of SO_2 and NO_x emissions, (2) developing new sources and emissions inventories for Edmonton and Calgary, and (3) summarizing and analysing five years of precipitation chemistry data. Point source diffusion and deposition modelling continued with (1) regulatory models being made available on floppy disk for personal computers, and (2) the EPA UNAMAP models being examined by a consultant for possible application in Alberta.

The Department continued its high degree of involvement in acid deposition research including liaison with various Federal/Provincial governments and industry. The Alberta Government/Industry Acid Deposition Research Program was initiated in 1983 to provide (1) a comprehensive understanding of the biophysical and human health effects of acid deposition, and (2) a scientific basis for sound, long-term environmental management and regulatory control of acid-forming substances. Biophysical research will focus on agricultural ecosystems. Acid deposition research in northern forested areas, and sensitive lakes in the Canadian Shield, will be undertaken by the Alberta Environment's Acid Deposition Research Program.

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ALBERTA ENVIRONMENT
Water Resources Management Services

Tom Tang
River Forecast Centre
Technical Services Division

During 1984, several new climatic stations have been added to our existing data collection network, which bring it up to a total of 44 precipitation or precipitation and temperature stations. Three new snow courses were also established, jointly by Alberta Environment and Trans-Alta Utilities, in the headwaters of North Saskatchewan River Basin.

The weather radar system is near the completion stage, and is operational this summer. This weather radar will provide a precipitation coverage over a 100 miles radius area in central Alberta.

In the last few years, NOAA satellite pictures were received on a weekly basis. This year we also collect digital tape data for further analysis. Attempts would be made to visually extract information such as snow covers, and break-up of ice in key lakes and rivers etc. Once a standard methodology of tape evaluation is developed, the series of images will be processed to determine estimates of basin snow covered area as the melt season progresses. Estimates of snow covered area will be verified by ground observations using snow pillows and snow courses data. The snow cover information obtained will be related to runoff conditions such as timing and volume, and eventually apply to runoff simulation models generated by the River Forecast Centre.

PUBLICATIONS

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ALBERTA ENVIRONMENT
Water Resources Management Services

GLENN GUENTHER
Hydrology Branch
Technical Services Division

The Hydrology Branch uses climatological data to determine the various parameters needed for analyzing water management projects such as river basin planning, reservoir design, and lake stabilization. The data is also used in statistical analyses (i.e. frequency distribution) and in developing river basin simulation models. Until recently, the climate data was processed manually, which is time consuming and required more manpower than what is available. This resulted in the development of the Climatological Data Base system (CLIM), which was designed for the Hydrology Branch to provide computerized access to Climatological data. The CLIM system is specifically designed to utilize many of the programs used by the Hydrology Branch for statistical analysis and also provides the maintenance and updating of the data base. The most recent use of the system was in the Radar Rainfall Intensity Study and in determining the probable maximum precipitation for the Oldman Dam Study.

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ALBERTA RESEARCH COUNCIL
ATMOSPHERIC SCIENCES RESEARCH PROGRAM

Agency Report

Presented at the Annual General Meeting
of the Alberta Climatological Association
June 4, 1985

Presented by Lub Wojtiw

1 INTRODUCTION

The Alberta Research Council, through it's atmosphere research program, acts as the central agency for weather modification research and operations within the province. In 1985, the program will be completing a 5-year field research project that is developing weather management capabilities in hail suppression and the precipitation augmentation to assist the economic development of the province. In this program, current aircraft cloud seeding technologies are being applied on hailstorms as well as an assessment of seeding clouds from the ground.

Some diversification in atmospheric sciences research has been achieved in recent years through consulting contracts in radar meteorology, satellite applications, hydrometeorology and air pollution.

2 MAJOR ACTIVITIES:

2.1 Hailstorm Seeding Experiments

Controlled seeding experiments on hailstorms using silver iodide, dry ice or a placebo accompanied by in-situ measurements using a research aircraft have verified the initial steps of the hail suppression hypothesis. Alternative hypotheses have also been developed. Analysis of time-resolved samples of hailstones collected at the ground have lead to a number of size distribution relationships that provide a method for predicting the numbers and sizes of hailstones for a storm. This technique will greatly enhance the ability to evaluate cloud seeding on a storm by storm basis. Experiments are continuing to determine if competition among growing hail embroys can occur.

2.2 Rain Experiments

Non-precipitating towering cumulus clouds have been randomly treated with silver iodide, dry ice or placebo to stimulate the precipitation process. Cloud physics measurements from two dozen analyzed seeding experiments indicate that cloud seeding can initiate precipitation from cumulus clouds. Research is continuing to determine the amount of precipitation produced with various treatments and the statistical significance of the results.

2.3 Snow

Limited cloud physics observations in winter clouds over the mountains indicate that precipitation mechanisms do not always remove all available cloud water, implying that some potential for snow augmentation exists. Case study analyses are continuing to determine the potential of snow augmentation.

2.4 Atmospheric Transport And Diffusion

In-situ observations in and downstream of the effluent plumes from tar sands processing plants in Northeastern Alberta have provided measurements to determine the conversion rates of sulfur dioxide and nitrous oxide gases in the atmosphere.

A plume tracing study was conducted in Southern Alberta in July using a ground-based cloud seeding device.

2.5 Climatological Studies

A preliminary study on the statistical modeling of agricultural crop production in northern Alberta was initiated. In addition, climatalogical studies of winter precipitation were continued, as part of the snow augmentation project.

2.6 Radar Studies And Computing Facilities

Research is ongoing developing a means of predicting damaging lightning flashes using radar information.

Small-scale rainfall intensity-duration curves have been obtained using radar data and polarization signatures of storm cells have been identified.

Computer software has also been developed to obtain from radar data storm intensity-duration estimates. This software has applications for severe storms where rapid, early assessment of storm intensity and location is often required for evaluation of possible damage.

Computing systems have been developed during the year including the following:

1. Automatic control and calibration of the radar systems was instituted.
2. The research aircraft data processing facility has been expanded providing additional software and tripling its capacity.
3. A meteorological data acquisition facility was put on line.
4. Hardware and software systems for the acquisition and processing of upper air data from radiosondes were developed.

2.7 Mesoscale Forecasting Studies

Ongoing studies of the mesoscale reactions of the atmosphere to approaching synoptic weather systems has confirmed the existence of preferred regions for convective storm development induced by the larger scale weather systems. Ongoing studies are continuing to improve the convective weather forecasting.

University of Alberta

Meteorology Division and Institute of Earth and Planetary Physics

(N. Aktary, K. Al-Jumily, R.B. Charlton, K. Finstad, R. Goodson, K.D. Hage, F. Hopper, P. Klivokiotis, E.P. Lozowski, A. Nowak, D. Phillips, E.R. Reinelt, J. Roesler, C. Sackiw, F. Safwat, G. Strong, D. Yiu)

A series of ice-accretion experiments were carried out in order to test and verify theoretical icing models. These experiments pointed out the critical importance of precise measurement of droplet size, as well as the necessity for modelling the formation of spongy ice.

An airfoil icing model is also being developed which includes a computationally-fast collision efficiency algorithm. Measurements have been made also on the spatial distribution of ice density in accreted ice. Mechanical and X-ray absorption techniques have been used. Two marine-icing wind tunnels are under construction.

A study of the meso- and synoptic-scale weather of May 1979 is nearing completion. Meso-scale regions of vertical ascent have been identified, which precede the onset of severe convective weather by several hours.

Studies continue of man-made snow, fog and cloud prevalent on very cold days in the petrochemical district of Edmonton. A finite-difference model of drainage airflow and particle dispersion has been used to generate vertical profiles of wind speed, air temperature and carbon monoxide concentrations for comparison with measurements obtained in the North Saskatchewan River valley in Edmonton. Recent models simulating the erosion of low-level inversion layers by entrainment have been combined with Brunt's radiative model for the nocturnal temperature profile.

The frequencies of reports of specific weather events in Alberta community histories have been used to identify weather extremes, such as dry years, wet years, severe winters, hailstorms, summer frosts, spring snowstorms, blizzards, dust storms and destructive winds, in the period 1880-1960. Information on the nature of the impact of weather extremes was used to develop objective "severe winter" and "drought" indices at Edmonton, Calgary and Medicine Hat. Destructive wind data from Alberta and Saskatchewan have been classified by severity of damage. While the frequencies of tornadoes in the two provinces appear similar, it has been noted that intense tornadoes are about twice as frequent in Saskatchewan. Surprisingly high frequencies of weak tornadoes associated with small cumulonimbus clouds have been reported.

A linear, hydrostatic model has been developed for the flow of stably-stratified air over a mountain barrier with an elliptical base. Analytical expressions for the surface pressure perturbations were used to study the differences between two- and three-dimensional flows. The horizontal divergence and lateral streamline deflection associated with the velocity component perpendicular to the mean flow were also considered.

A thesis project has been completed on the use of satellite data in determining precipitation from convective clouds in Alberta and Western Saskatchewan. The results obtained suggest that rain accumulation is inversely proportional to temperature, with enhanced rates of precipitation from colder clouds, or when the temperature difference between cloud top and tropopause is large.

Work is in progress on the cohesiveness of upper-air soundings in space and time. in pressure, temperature and wind are examined from data sets obtained from serial releases of radiosondes.

Several years of satellite images have been examined for cloud configurations that do not fit readily into current cloud classification schemes, with the aim of identifying causes and mechanisms of cloud development which are not associated with fronts and cyclonic systems. A related project concerns itself with the transport mechanism and distribution of Arctic haze.

A climatology is being formulated of upper-air parameters relevant to the incidence and control of forest fires. A catalogue of vertical wind and temperature profiles is being compiled for specific sites within the boreal forest regions of West-Central and Northern Canada.

A Ph.D. project has been completed into the problem of determining the onset of turbulence. An algorithm has been devised for examining the nature of the solutions of the Navier-Stokes equation during transitional conditions, from stationary states to solutions periodic in time. The mechanism for the generation of turbulence assumes a sequence of three Hopf bifurcations on the N-S equations.

BUSINESS MEETING

ALBERTA CLIMATOLOGICAL ASSOCIATION

9TH Annual General Meeting

4 June 1985

The Alberta Climatological Association 9th Annual General Meeting was held on the afternoon of June 4, 1985 following the technical session. The meeting was held in room B2-05 of the new Business Building on the University of Alberta campus and was attended by 12 of the 35 registered attendees of the technical session.

1. Proceedings of the 1984 Annual General Meeting

Serge Dupuis informed the meeting that the 1984 proceedings have been printed and are available from Alberta Energy and Natural Resources. A large number of copies have already been distributed.

2. 9th Annual Meeting Program

The program covered many aspects of the application of climatological data in Alberta. Theoretical aspects of evapotranspiration modelling were presented, data acquisition in the Marmot Basin Project was reviewed, experiences gained on the use of snow pillows were discussed along with the ongoing projects to provide site specific meteorological data in support of the 1988 Olympics. Copies of the papers will be included in the Annual General Meeting report.

3. Business Meeting

The next annual general meeting has been suggested for the second week of February in order to coordinate with the Winter Cities '86 international forum to be held 15-19 of February. Members were asked for suggestions as to an appropriate theme for the ACA general meeting keeping the forum in mind.

A position became available on the executive with the departure of Dr. R. B. Charlton. Ms. P. Gourlay of Alberta Environment will fill this position.

The meeting was closed by Serge Dupuis at 4:00 p.m.

27/06/85

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